Centre for Geo-Information

Thesis Report GIRS-2015-28

Facing the unfriendly street

*M*apping critical walkability factors of elderly people walking with a Rollator, in the outdoor public space of Amsterdam the Netherlands.

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Abstract

This research aims at grasping the critical walkability factors that elderly experience while walking outdoors with a rollator, and visualize them to raise more awareness and trigger possible action at decentralized governments. This may increase walkability walking activity of elderly people. Consequently it may support health, the capability to live independently and grow old in their own house and environment. All may contribute to less need for healthcare and so reducing costs for elder care.

This is done, first, by finding the critical walkability factors for the outdoors urban environment through, literature study and interviews with elderly and the local government. Second, after selecting the most prominent factors, these will be mapped by using existing geo data and gis analysis to test its suitability and detail required. Third, a set of geo data is collected by measuring several rollator walks, where the rollator is mounted with GPS and an accelerometer to map movement and vibrations. Finally, the existing and collected data will be analysed and combined by using a method for change point detection.

The 3 most mentioned walkability hindrances named are, one, wrongly parked bikes and cars. Two, sloping pavements. And three irregular pavements. Surface hindrance was measured with an accelerometer on a rollator for 8 different surface types. Two routes with GPS and accelerometer were successfully covered and analysed. Yielding in data on, speed, distance, vibration movement. The slope map added height and slope to the route characteristics.

In conclusion, this pilot shows potential for using smart-phones with a simple accelerometer to detect obstacles and surface hindrance for rollator users. Though, in this study too many measurements failed no hard conclusions can be drawn and further, better research is needed too improve the amount of detail and accuracy in the measurements. The use of AHN data with a slope map did show good change point indication where a bump or ramp was taken. Though the accuracy of a smart-phone GPS, again, here gave not enough accuracy to draw hard conclusions from these measurements.

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1. Introduction

Chapter 1 will contain the introduction, the problem definition, the goal and objectives and in the end will explain the report structure.

1.1. Introduction

1.1.1. Challenges for an ageing population

The Dutch population is getting older. In 2014, 18% of the population was older than 65. In 2040, the demographic ageing will reach its top, 26% of the population will be 65 years and older. [20] Amsterdam has less demographic ageing compared to the whole of Netherlands [20]. Though, already 22.4% of its inhabitants is older than 55. (182.000 inhabitants on 01-01-2014) One fifth of these elderly is older than 75 and 13% older then 80. [20] By 2040, Amsterdam will have 11 to 16 percent more elderly inhabitants of above the age of 65. See figure 1.1.

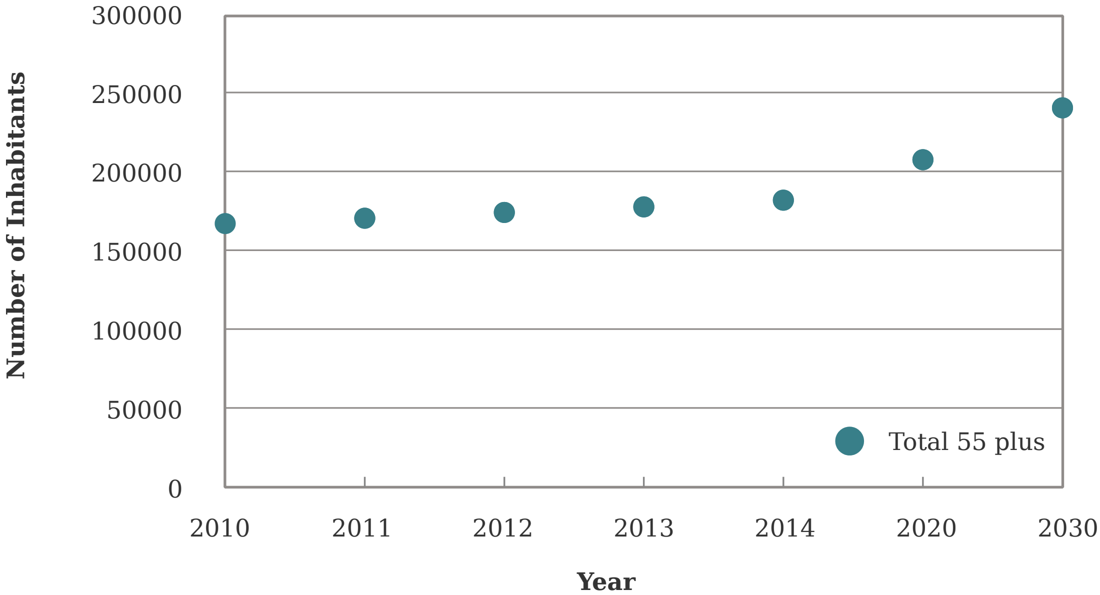


Figure 1.1.: Total 55 plus inhabitants Amsterdam. On the 1st of January 2010-2014 & Prognosis (2013) for 2020 and 2030. (Hylkema et al. 2014)

Since 2015, the Dutch municipalities are responsible for the care of elderly, the assistance and support. But fewer funds are available for decentralized governments to spend on health care. Next to that, the growing share of elderly is expected to demand higher funds regarding health care, social care and retirements wages. All these developments challenge to seek solutions to balance cost and services. Synergizing policy solutions between different policy areas at a decentralized level may help with the solution. [20]

The new trend in elderly care, is letting elderly live longer independently [26, 38] also called active ageing [3]. The Amsterdam municipality aims its elderly strategy in the StructuurVisie for 2040 to let older inhabitants live independently, as long as possible, to reduce health care costs. Growing old in the own house, is welcomed by a lot of older inhabitants of Amsterdam. [8]

1.1.2. Elderly pedestrians

Living independently means, being mobile for personal care and have access to the public space for grocery shopping, social contacts and physical activity. In urban areas, elderly depend on walking for their everyday life and it is a key aspect of daily life to stay independent. [18]. In many countries, 30 to 50% of older people's journeys outside are made as an pedestrian [34]. In the Netherlands, about 23% of the trips made by elderly, are made by foot. Overall, walking as from of transport, happens more in urban areas then in rural. (See figure 1.2) In Amsterdam 31% of the main trips are made by foot. In general, Dutch elderly depend more on walking then other age groups as seen in figure 1.3 from a pedestrian study by CROW. [39, 33, 11]

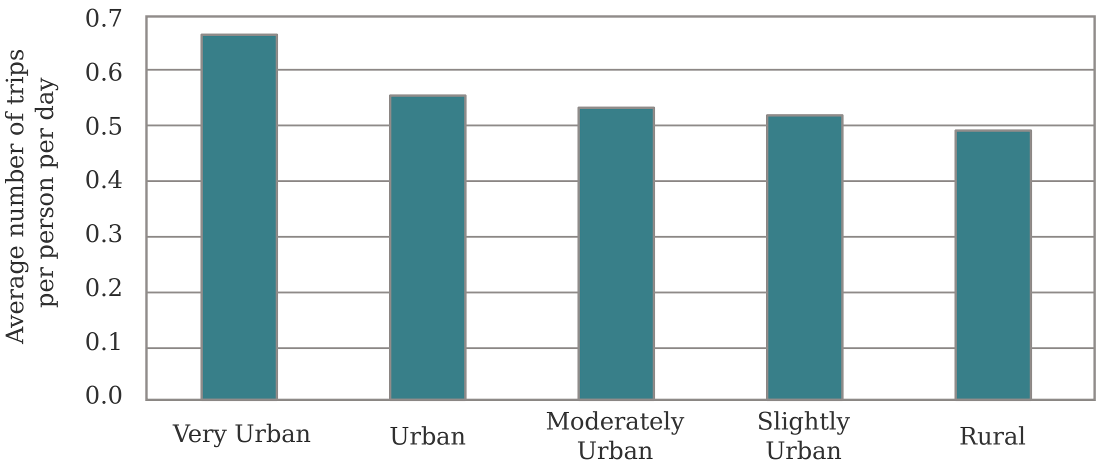


Figure 1.2.: Walking trips made in specific environment. (Sauter et al. 2010)

The main benefit of walking is the importance for the health of elderly. [7] Regular exercise has a positive effect on the fitness and physical health. Also lowering stress and improves the overall well-being. There is a well-established correlation between health benefits and regular physical activity. [3] Also, for elderly walking is the favoured form of physical activity. [7] See figure 1.3.

In conclusion, outdoor physical activity, particular walking, seems the key role in the maintenance of functional independence at old age. [29] By enabling mobility, elderly can keep control of their own life by being able to move outside independently for everyday tasks and social contacts. [26] Walking keeps them fit and healthy and so increases the chance of longer and independent life. Overall, contributing to a better quality of life.

1.1.3. The Rollator

A lot of elderly use a rollator, or wheeled walker. It helps maintaining mobility and continuing an active lifestyle. It provides stable support and may help avoid falls. Walkers are an important

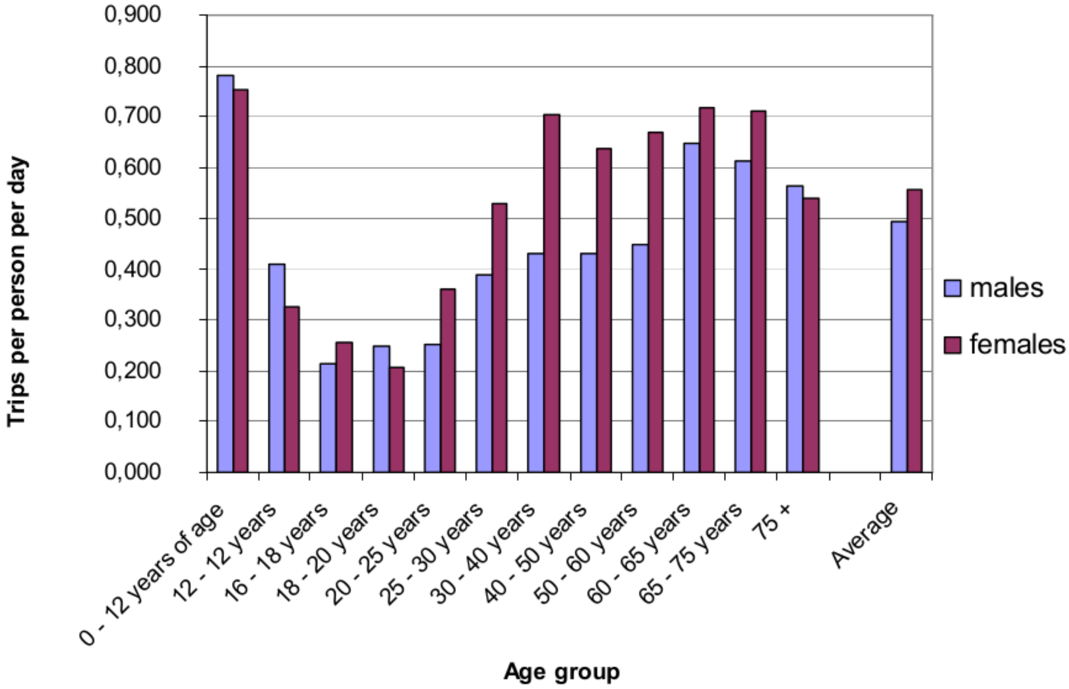


Figure 1.3.: Number of trips per person per day by age group. (NL, 2007 from [30])

assistant for elderly who face difficulty walking and maintaining balance. The exact amount of rollator users in the Netherlands is unknown. An estimation in 2002 states 160.000 to 300.000 rollator users in the Netherlands [41] and the average age of rollator users is 77.7 years old, according to an article in Trouw. [12] For further references we will refer to the wheeled walker as a rollator. Indicating a hand held walker with four wheels.

1.1.4. Mobility problems

Getting older means; being less mobile and more fragile. [41] In general, about 50% of the pedestrians in the Netherlands have limited mobility abilities and around 10% of the population has severe difficulties walking and sojourning in the public space. [33] Table 1.1, shows the number of Dutch inhabitants with limited mobility, with the largest group formed by elderly above 65. Also the prediction for 2030 shows an increase in elderly with mobility problems. [33]

Yearly, 18.000 elderly of above 55, needed emergency care after a fall on the street. This means, that every 30 minutes, an elder adult falls so severe that care in the emergency room is needed. [41] About 2.300 elderly of above 55, need emergency care after a fall with a rollator. [41] One of the six falls with a rollator is outdoors. (380 falls a year) [41]

Falls on the street without rollator occur more than falls with a rollator (18.000 to 2.300), but the latter cause more severe injuries. The medical costs for a fall with a rollator are inexplicably higher than a normal fall on the street. Average costs of 12.000 Euro to 4.200 Euro(table 1.2). An indication that a fall with a rollator leads to more serious injuries, then a fall with bike or scoot-mobile. [41]

Fall accidents on the street occur due to behavioural factors (61%) and environmental factors (58%). Falls with a rollator also occur because a walker may be difficult for the user when the user is too weak to lift, or the rollator unstable or too heavy to handle. A user needs strength and coordination to operate a rollator effectively [15, 45]. One third of the falls on the street is because an elderly tripped (35%), over a stone or tile (10%) or a curb (4%). One fifth slipped (20%) on a slippery surface (12%). [41] Environmental influences noted are irregular surface (43%), obstacles and irregularities (31%), bad maintenance (16%) and slippery areas (13%). [41]

Table 1.1.: Predicted number of people with limited mobility, Netherlands (Sauter et al. 2010)

-	2005	2010	2015	2020	2025	2030
Perc of people w limited mobility	6.1	6.3	6.7	7.0	8.2	9.4
Number Younger than 65	340.000	340.000	350.000	350.000	360.000	360.000
Number 65 - 79	250.000	270.000	310.000	360.000	400.000	430.000
Number 80+	410.000	430.000	460.000	490.000	660.000	830.000
Total number	990.000	1.050.000	1.130.000	1.200.000	1.410.000	1.620.000

Table 1.2.: Yearly average and total medical costs for 55+, to type of accident. From Letsel Informatie Systeem 2006-2010, VeiligheidNL [13]

	Average costs	Total costs
Private- and traffic accidents on the street	€ 4.500	€ 220m
Fall on the street	€ 4.200	€ 82m
Simplex bicycle accident	€4.600	€ 71m
Rollator	€12.000	€ 33m
Scoot mobile	€ 6.900	€ 8,9m

1.1.5. The contribution of the built environment to walkability

For elderly, who are more vulnerable, environmental attributes can be barriers to an active engagement in urban life. The quality of the immediate environment is a significant determinant of elders well-being, independence and quality of life. [43] Because these environmental details are critical for what the older inhabitants can manage in their everyday lives [34, 36, 10, 3] creating a walking-friendly environment is important for their independent mobility. [33] The few studies that explore the older inhabitants and pedestrian-ism are arguing that good neighbourhood design can influence physical activity, health and consequently can lead to a longer life time of independence. [43, 29, 28, 6, 32, 10] The environment can have a powerful effect on the amount of walking activity undertaken by older people, thereby influencing their capacity to maintain their well-being and independence [43]

The assessment of a neighbourhood design that supports elderly can be based on walkability.

Walkability is the measure of how friendly the environment is to walking. The extent to which the built environment supports and encourages walking. By being friendly, giving comfort and safety, and provide aesthetic appeal. Vine et al. describes walkability as, the extent to which the built environment supports and encourages walking, by providing pedestrian comfort and safety, with reasonable time and effort and offering visual interest throughout the network. [43] Borst et al. states that walkability is an index of the quality of the neighbourhood. The factors determining it, include, residential density, land-use-mix, street connectivity, aesthetics and safety. [7]

The report from CROW about pedestrianism in the Netherlands(CROW is explained in next section) states that investing in pedestrian policy and making a pedestrian-friendly environment lets the elderly live longer independently. [39, 11] This means, it requires the environment to provide the best conditions for even the most frail and weak sub-group.

Previous studies have found a relationship between neighbourhood characteristics, physical activity and related health aspects. [7] Aspects of the built environment, in particular neighbourhood design, have been found to influence the amount of physical activity undertaken by inhabitants of urban neighbourhoods, [7] access to public transport, nearby goods and services, walking for leisure, social interaction and engagement in the community. [43] In order to increase the quality of the environment, we need better insight into the influence of the urban design on the walking behaviour of elderly to make it useful for policy and design.

1.2. Problem definition

1.2.1. The forgotten pedestrian in policy

There is little research carried out on pedestrian satisfaction in the Netherlands, to the fulfilment of one's wishes, expectations and needs. The sparse information about what dissatisfies the pedestrian comes from complaints at local authorities, questionnaires or internet sites. The Pedestrian Quality Needs Project(PQN), identifies what people need for safe mobility in the public space. The project was conducted from November 2006 until November 2010. The main objective was to provide knowledge of pedestrians' quality needs to support walking conditions it the EU. They provide an extensive report on what people need to walk. Also country reports stating the current status of pedestrian knowledge in all participating countries. [33] The PQN report of 2010 on walking in the Netherlands states that serious problems and deficits in Dutch pedestrian-ism are partly or totally hidden from public, scientific and political attention. [30] In short, they state the following about pedestrian knowledge in the Netherlands:

The vicious circle of no data- no awareness - no priority - no research - no data, needs to be broken. [33, 30]

This, aiming at pedestrian-ism in general. With regard to in specific elderly the PQN report states that large numbers of people already have trouble performing walking and sojourning tasks, because of the ageing of the population these numbers will only increase. [33] Therefore, prevention of falls is important, in regard to the safety of pedestrians, which is also an age related problem. [33]

Also the publication about pedestrians in the Netherlands from CROW (2014) [11], states that pedestrians are forgotten in policy and design. CROW is a national knowledge platform for infrastructure, traffic, public transport and public space. A non-profit organisation providing guide-lines for the design, policy and projects with regard to the design of the public space. They state that walking, though one on the main forms of transportation, gets less attention then bicycles, public transport and cars. Pedestrians get more easily forgotten in policy design and maintenance plans. There is a need for a more systematic approach. [11] There are 2 reasons why walking is not part of policy and design plans; first, there is a lack of knowledge about how investments contribute to the tackle of problems. Second, there is no insight how walking can be optimised in policy, design and maintenance plans. [11] With regard to elderly as pedestrians in specific, they state, that a well accessible pedestrian network, and attractive walking routes can contribute to the independence of elderly. Children and elderly are vulnerable in traffic, and elderly pedestrians above 75 have the biggest risk of being victim to traffic accidents with severe endings. [11]

MENSenSTRAAT is a network for independent mobility by foot or bike, focussing on the more vulnerable users of the public space. They constructed a pleading call for improving the public space with regard to elderly pedestrians and state that the direct outdoor environment, is crucial for elderly to live independent and stay healthy. Weak sub-groups are often overlooked in the design process and the local governments often forget the importance of street design for the elderly. MENSenSTRAAT states that this needs more attention. [26]

1.2.2. The forgotten pedestrian in research

Next to the forgotten pedestrian in policy, also little studies can be found on walking behaviour and pedestrians in general [43]. A limited number of studies can be found that look specifically at older people's use of the outdoor home environment, how they use it and what problems there are. [28, 36] Even less studies focus on for elderly walking with a rollator outdoors. [36, 34, 28] Most studies about elderly, mobility and rollators, focus on the interior conditions and accessibility indoors of public buildings, and residences. [11, 33, 42] The outdoor environment is significantly important to elderly, but despite this, little research has been conducted on this. [36] In addition, little knowledge exists about the factors influencing walking behaviour of elderly. What do elderly perceive as being unpleasant? Moreover, factors that are known, do not always find an integrated place in policy, design and maintenance plans. Let alone, hardly any research can be found that focusses on methods to quantify or map the possible problematic factors.

1.2.3. The forgotten pedestrian in data

Because in general there is no research on pedestrians there is also no data [33] Walking to other forms of transport, multi-modal walking, is almost as extensive as walking from door to door, but is often not included in statistics. Therefore, the numbers are often underestimated in the interest of walking when looking at mobility statistics. [41, 33] The PQN report gives several reasons for this lack of data:

1. Pedestrians are low on the transport agenda. Lack of sensitivity and political will on collecting data on walking. No counting means no data, no data means no counting

2. Data that is collected is fragmented and inconsistent. Lack of common standards

3. Indicators and methods for measuring transport are not appropriate for walking
4. Existing information is not edited for use
5. Existence of data is not known or hard to access

The vicious circle of no data- no awareness - no priority - no research - no data, needs to be broken. [33]

People that have mobility problems, are struck hardest by obstacles in the public space. [38]

1.2.4. GIS opportunities

GIS technologies and databases can provide great potential for studying the environment and neighbourhood characteristics that influences outdoor walkability quality among older people [43] and by doing so, fill a bit of the knowledge gap for decentralized governments and urban planners. While the role of geo-data in urban design is recognised nowadays, [25] mapping the environment and the problems with GIS gives more understanding and customized information about the city to its city planners in order to develop new interventions and enhance walkability for rollator users. [25, 37] GIS is a strong medium to provide urban planners with the data needed to make the urban area more friendly to rollator users and make cost-effective prioritized interventions. It is a rather easy approach to enhance the knowledge about the urban environment, and to locate certain obstacles and flaws that affect accessibility for the impaired citizens. [37] Here we will look at the opportunities that available geo-data in the Netherlands and analysis provides to fill some of the knowledge gaps and make the obstacles for elderly pedestrians more visible. It helps makes visible the way that the build environment is often distorted and hostile for the mobile impaired. [25]

1.2.5. Lack of detail in (geo) data

The scarce amount of studies about the elderly pedestrian, stated that more accurate, detailed and up to date data is needed to map walkability indicators for elderly, then the current and accessible geo-data can provide. [42, 23] Such detailed data is needed, because every stone counts in regard to frail elderly. [25, 23] Importance of small details in relation to the larger infrastructure seems needed to map the walking restrictions in the outdoor activity space of elderly with a rollator [36, 34]. Will GIS be able to map sufficient detail needed for the critical walkability indicators for elderly with a rollator?

1.3. Goal & Objectives

This research aims at grasping the critical walkability factors that elderly experience while walking outdoors with a rollator, and explore the possibilities of geo-data and GIS analysis to visualize them, to raise more awareness and trigger possible action at decentralized governments. This may increase walking activity of elderly people. Consequently it may support health, the capability to live independently and grow old in their own house and environment. All may contribute to less need for healthcare and so reducing costs for elder care. So the overall objective of this research is to analyse the critical walkability factors for elderly people depended on a rollator, in the urban outdoor space. The case study is Amsterdam, the Netherlands. To achieve this overall objective, the following sub-objectives and research questions are developed:

1. Find the critical factors for walkability in the urban outdoor environment for elderly depended on a rollator.

2. Map and analyse these critical factors,

   a) by analysing existing and available geo-data and testing its suitability and detail required

   b) by collecting geodata (measuring rollator movements with an accelerometer) and analysis

   c) by comparing these the two data sources(by using the change point method).

1.4. Report Structure

This report will exist of 5 chapters, including this introduction chapter. Chapter 2 describes some background concepts and projects related to this one. Which are the inspiration and reference to support this study. Chapter 3 starts with a sketch of the research area and continues to provide per research question, the data, preprocessing and methods used. Figure 1.4 illustrates the structure of this report. The final chapter presents the conclusion per research question, the discussion and recommendations for future work. Each chapter in this report opens with a short outline of its content.

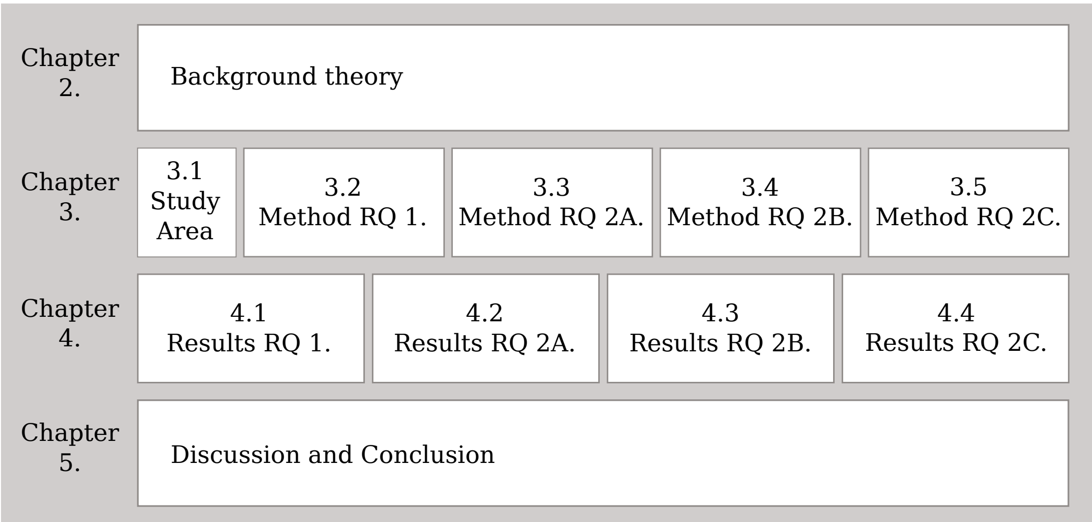


Figure 1.4.: Report Structure

2. Background theory and concepts

In sections 2.1 and 2.3 some concepts used in this research will be clarified to have unambiguous use of terms. Section 2.2 will tell more about the Puccini method which is used for the design of the public space in Amsterdam. This chapter will be finished with summaries of related literature (also part of section 4.1) which helped forming this research and provide reference and support for the data and methods used.

2.1. Pedestrians

A pedestrian is a person, by foot, with or without helping aids, that moves in the public space. The person is not a driver but a road user. Also persons with a wheelchair, rollator, roller-blades, skateboard or children's bicycle, as well as persons walking with a bike, scooter or motorbike in the hand are pedestrian according to the Wegenverkeerswet voetganger. [11]

Mobility is the freedom to choose to travel and sojourn in the public space, being able to make the trip, regardless its distance. Pedestrian mobility differs from other modes of transport, for it almost part of all other trips. [33]

Sojourning is an important indicator for quality of public space, it includes activities as; recreational walking, waiting and hanging out in the public space. [33]

The Netherlands is climatic and geomorphological very favourable for walking. [33] In cities almost all streets have two sided side-walks. [33] Though, cycling is perceived much more important in the Netherlands as seen in the pecking order in traffic: public transport, car traffic, scooter, bicycle, pedestrian. In some regions of the Netherlands the soil is rather soft and peaty, in these circumstances the pavement has to be renewed every few years, to prevent sinking.

2.2. Puccini Method

The Puccini Method is the Amsterdam tradition for the design of the public space and formulates design principles. Public space includes all non-build-up space, open and accessible to people. The Puccini Method contains all points of policy, to the detailed design, technical details and material lists. It contains four modules, red for streets, green for vegetation, blue for water and water banks, and last, purple for street furniture, street lights and public transport stops. The Puccini method is the handbook for the municipality to maintain and design the public space. It is not a policy design book. [2]

The Puccini method contains 6 convictions: [2]

1. **Choose, not share** The streets are used more intensive and pressure increases. Often the usage pressure is higher then the available physical area. Therefore the available space has to be assigned to one use, not shared.

2. **Simplicity and obviousness** The pbulic space should be user-friendly, sustainable, strong in simplicity, timeless and obvious. With simple material and simple design, reaching for good quality.

3. **Craft and skill as a basis** Craft expertise is the basis. Not only designing inside, but going out on the streets with work experience is the key.

4. **Crucial eye for detail** Detail for material use, time, financial resources and facing problems that have to be solved.

5. **A good plan is maintainable** After the realization of a street or square it still has to be maintained. The plan has to take the maintenance into account for the future.

6. **Cooperation** A lot of specialised disciplines are concerned. Throughout the whole process it is important to communicate until the end product is realized.

Amsterdam is a cultural historic city, with many urban designs from different time periods. The historical city centre, the 19th century canal-belt, the 20-40ties en the postwar city. The urban design has to suit the cultural historic character of the city. For every urban style zones there are material lists and standard design details. [2] A map of Amsterdam indicating where each urban time zone is located can be found in annex A.3.

2.3. Walking behaviour

The rate of walking for a person is determined by many factors, environmental influences, personal influences or behaviour and biological influences. Here we focus on the environmental influences, in specific, walkability of the environment. Walkability is one of the many important determinants that influence the walking behaviour of elderly [43]. To show where walkability is positioned, next to terms like accessibility and mobility, we try to sketch an overall overview of the walking outdoor determinants. Based on the behaviour scheme of Bartolomew. [5] Figure 2.1 represents a small part of the personal and environmental determinants that influence the criteria for walking behaviour of elderly. It is incomplete as this is not a behaviour study, but gives a good insight in what is and is not included into the term walkability. First of all, the personal determinants personal health, previous experiences and perceived self-efficiency are not part of this study. Though, what not to forget is, that these are often influenced by the environmental determinants. Walkability is part of the environmental determinants, terms used in dedicated studies are accessibility, walkability, safety and activity space. [43] Accessibility is the ability to access needed facilities and enable persons with disabilities to gain access through for example elevators, audio signals, walkway contours etc. As stated in the previous section, mobility is the freedom to travel in the public space. Here we assume that all elderly have the freedom to go outside, make use of the public space and access the facilities they need. The quality of these routes, the friendliness and the safety are gathered in the walkability determinant. So while a person in walking and accessing the public space, how user friendly and how much effort does it cost to cover these routes?

The individual path selection criteria of Golledge can be placed next to this scheme to show how

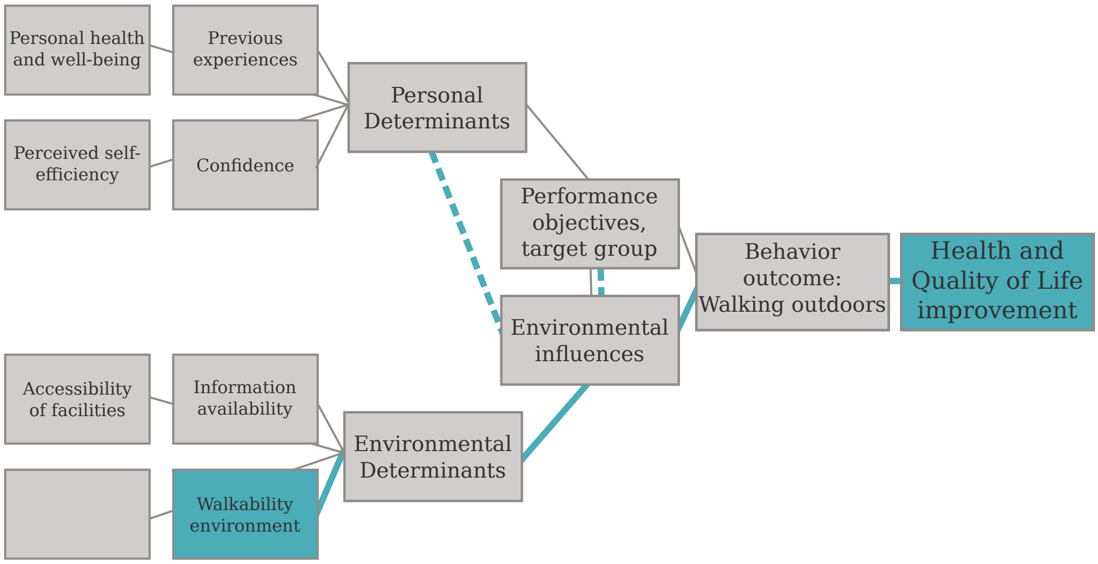


Figure 2.1.: Walking Behaviour Scheme (Source: Boeijen, based on Bartholomew 2011)

they influence the actual choice for walking. All the personal and environmental determinants together, make an individual decide to go by foot or not to a certain destination, the behaviour outcome. Then when choosing the route and having experiences on these routes influence the choice for the next time the user wants to walk that route and which path will be followed. [19] The individual path selection criteria by Golledge knows 3 phases [19]:

1. Choosing destinations
2. Making a route
3. Implementing and feedback. Confirmation or change?

The first two phases are influenced by the many determinants, while the last phase provides new knowledge and experience again influencing the next time a user wants to walk outside. Increasing or decreasing the influence of the previous determinants.

2.4. Walkability factors from literature

From several literature studies dedicated to pedestrian-ism, elderly pedestrians, mobile impaired pedestrians, rollator users, walkability studies and walking behaviour, a list of possible walkability criteria for elderly with a rollator is created. The criteria are influenced by a wide variety of factors of the urban environment. They can be tangible and physical or intangible and more related to personal perception and feelings. [42] Some criteria focus more on the broad environment of living, while others more on personal detail in the direct environment.

The most important researcher aiming at the elderly as a pedestrian outdoors is Agnete Stäl. The rollator is a Swedish invention, and Stäl is a Swedish researcher focussing a lot on elderly pedestrians with rollators, about their accessibility and safety in the public space and how interventions in the public space impact the elderly pedestrian. Stahl is one of the few that looks specifically at the elders perception of the built environment and how specific interventions can help rollator walks be perceived more attractive. [36, 34] An important part in her research, is user involvement, which leads to research with greater relevance and improvements to outdoor pedestrian environments based on the problems identified by elderly people. Stäl claims to be among the very few examples of user involvement in research targeting at societal panning. A mixed-method approach is used emphasising involvement of elderly people, not only as sources of data but also as partners. [36] Conclusions from the studies are that different individual background variables influence older peoples' perceptions of the walkability factors. Perceptions on the outdoor environment are influenced by sexes, functional limitations, use of mobility devices and age. For example, physical barriers in the outdoor environment become increasingly evident with increasing age, among older people with functional limitations and user of mobility devices. [34, 46]

Several other studies, not necessarily aiming at elderly with an rollator or user involvement, made an overview of walkability criteria for pedestrians, elderly or the mobile impaired. For example Verschuur [42] provides a list of parameters affecting route attractiveness and the studies in which its found, for elderly pedestrians. Duncan (2011) [14] provides a whole list of walkability indicators they use for calculating a WalkScore for the general pedestrian. Rosenberg [31] provides a summary of barriers and facilitators in the built environment for mid-life and older adults with mobility disabilities. Wennberg studies a whole list of usability factors and their statistical significance, divided into categories, physical barriers, orientation and warnings, bus stops and shops, orderliness and benches and stairs, for elderly pedestrians [46]. All these lists and other studies are used to create an own overview in order to filter out the most important walkability criteria for elderly with a rollator. This list can be found in Annex A.2

For making all the criteria more orderly, they are first subdivided into tree levels of where they could occur.

1. Pavement level
2. Street level
3. Environmental level

Though, this didn't seem sufficient. Some weather related and temporal issues that occur, could not be placed in this subdivision as they can occur over all these tree levels. Also crossings form a own special niche in the levels for it is not part of the pavement or the street. Therefore these are added to the tree levels mentioned above.

1. Weather or temporal level
2. Crossings

Also the factors could be assigned to different categories, some had to do with accessibility and other with the quality of the environment. Five categories can be distinguished. These are inspired by [4] and [31].

1. Accessibility
2. Quality
3. Obstructions or barriers

4. Route attractiveness

5. The feeling of safety

Accessibility is about the access and presence of the pavements, if there is a pavement available and destinations can be reached. Some examples of factors are: the availability of public transport nodes, availability of bridges, availability of ramps to the pavement a.o. The quality is about when a pavement or stair is present, what the quality is. This could include things as a non slippery pavements, the slope of bridges and the slope of the pavement. Obstruction contains tangible objects that are in the way, temporary or stationary. Like protruding portals and facades, blocking commercial signs or green maintenances so branches are not hanging over the pavement. Route attractiveness is more about the feeling one has towards the routes, the attractiveness can go down with the presence of dog droppings on the pavement, litter and garbage on the streets. While it can go up with the availability of resting benches, public toilets, green and trees along the route. The feeling of safety includes factors as enough time to cross the street, good overview while crossing a street, vehicle-pedestrian interaction, speed limits, presence of street lights, the amount of criminality and many others.

2.5. Related literature for methodology

Literature that discusses the possible methodologies to make walkability quantifiable are rare. Matthews et al. (2011) develops a model for mapping accessibility for wheelchair users and comes closest to this study. Svensson (2010), researched accessibility in particular, a determinant which will be left out in this study. Finally, Walkscore from Duncan et al.(2011) is a more general project, focussing on mapping neighbourhood walkability to enhance physical activity among children, adolescents and adults. But provides an interesting method for mapping several walkability indicators. In order to measure walking behaviour of elderly with a rollator the term to look for is: Smart Walker. The studies from Wang et al.(2015) and Weiss et al.(2014) focus on the technical aspect of measuring rollator movements and gait characteristics with an accelerometer. The next sections, will give a more detailed summary of the above named articles.

2.5.1. Mapping walkability

Obviously, a wheeled walker and wheelchairs have a lot in common. Therefore, also literature studies aimed specific at wheelchairs can provide useful insights for rollator research. Matthews et al. 2003 uses a GIS based system to show that the built environment is often distorted and forms a hostile space for wheelchair users. [25] MAGUS, modelling Access with GIS inUban Systems, is a multi-criteria assessment model using quantitative and qualitative techniques to provide urban planners and disabled people with up-to-date, detailed and customized information. This, to help them plan and manage their access and mobility in urban areas. At the same time, this provides planners a system that hep them evaluate the effects of their design decisions on the mobile disabled pedestrians. [25] The model is based on real-world perceptions, experiences and needs of disabled people. The eventual choices included in the model area, show all possible routes, avoiding bad surfaces, avoiding slopes width a gradient of more then 4% and using only controlled crossings. A drawback in the data was, that no information is held on pavement centrelines, which, forms the starting layer within a GIS model. The solution was manual plotting, and taking into account building outlines, walls, road edges and other linear and point details. So a precise pedestrian route can be mapped. The MAGUS project has been installed at various places in the UK, the report states new fund were available for the MAGUS model to become web-based. [25] This however was in 2001. Recent developments on the MAGUS project are unknown.

Svensson (2010) [37] uses a GIS-model to map and measure accessibility of the urban environment for citizens whit impairments. In order to improve accessibility planners require knowledge about the location of obstacles and how these effect accessibility. Data on the physical environment of different Swedish towns has been collected in order to identify neighbourhood specific characteristics. A digital model of the town's pedestrian network contains information about: slope. height of kerb stones, type of pavement, width of a side walk etc. They found that only a fraction of the population is able to reach a bus stop from their home, if they are allowed to use only those parts of the pedestrian network that are defined as usable, for mobile and vision impaired citizens. Also the study shows that accessibility varies, with different neighbourhood types. [37] Overall the study demonstrates that a GIS system could be used to gain vital information about the need for improvement in the built environment. Rather easily, the knowledge about the urban environment in enhanced how certain obstacles and flaws affect accessibility for the impaired citizens. [37]

WalkScore is developed for assessing neighbourhood walkability by Duncan et al.(2011) [14]. The WalkScore algorithm is based on a GIS indicators of neighbourhood walkability and ranges between a score of 0-100. It is developed for a large area in four US metropolitan areas with several street network buffer distances, 400, 800 and 1600m buffers. Duncan et al. does not focus on the mobile impaired but at improving physical activity among children, adolescents and adults. Overall, WalkScore presents an web-based geospatial technology to estimate neighbourhood walkability in an interesting way, a weighted multi-criteria method, which could be used as inspiration to extent such methods to a more detailed survey for the mobile impaired pedestrian.

2.5.2. The Smart Walker

There are a few researches on making a rollator more smart by using sensors; the Smart Walker. Most of these studies focus on fall protection, early warning systems or indoor navigation. There are functions such as sensor assistance, health monitoring, navigation help or cognitive assistance, obstacle avoidance and fall detection. [44] Most studies using an accelerometer as a sensor, calculate gait parameters such as; step length, gait cycle, step width and gait variability. [44] Often these studies are done in laboratory settings, using high quality sensors and sensors attached to the body. This research aims at obstacle detection, with the help from detecting the movement of the rollator. On this, no specific literature could be found.

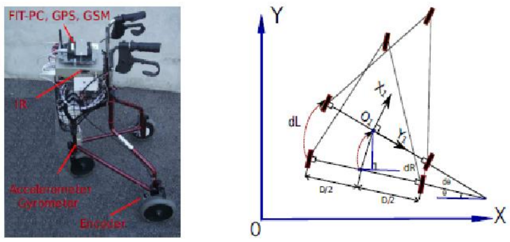
Weiss et al. (2014) uses a smart walker to detect walking behaviour change in real time with an accelerometer mounted on the rollator. [45] No sensor on the user is needed, but the walking behaviour is detected based on the motion transfer by the user on the walker. The goal is to identify five different classes: no movement, movement, slow, normal and fast. They confirm that walking behaviour changes can be detected by using a 3-axis accelerometer sensor on the walker. [45]

Wang et al. (2015) uses a standard 4-wheel rollator with a defined walking frame, where the accelerometer is positioned in the middle point between the two rear wheels. By doing this the exact distances to the wheels are know and from this the position change of the walker can be determined. By using a high cost motion capture system, the calculated trajectory's and

Fig. 1. (a) Hardware setup; (b) Accelerometer axis configuration.

Figure 2.2.: Rollator with accelerometer axis configuration. From Weiss et al. [45]

T. Wang et al.



. 1. The instrumented walking aid **Fig. 2.** Simple kinematic model of the walker

Figure 2.3.: Rollator research set-up. From Wang et al. [44]

the gait or step detection, are validated. Wang was able to calculate the displacement of the walker during every step with an accuracy of approx 1 cm. [44] By comparing a group of young adults with group of elderly people, Wang found the the walking accuracy of the elderly is lower but that step length, step period and walking speed between the two groups has no obvious difference. The classical gait indicators are not sufficient or sensitive enough to evaluate the fall risk of elderly. [44]

2.5.3. Concluding

The MAGIS model of Matthews and the Walkscore from Duncan, both use a multi-criteria model. MAGUS including criteria as avoiding slopes, cobbled pavement surfaces and using controlled crossings as input. Walkscore, was more general, and focussed more on accessibility, using network length, network nodes density ect. Svensson focussed more on comparing different neighbourhood designs and collected data on slope, height of kerb stones, type of pavement and width of a side walk. Both Wang and Weiss made use of a non-intrusive measurement method, were no devices were placed on the participants but only on the rollator. In order to measure gait characteristics and walking behaviour.

For this study both methodologies will be combined. Firs, the basic mapping of walkability factors through using existing geo-data and analysing if their detail is sufficient to do this. Second, using the concept of a Smart Walker with an accelerometer to map more in detail the effects of obstacles in the build environment on the walking behaviour and movement characteristics of the rollator.

3. Data and Methods

This chapter starts with a small section on the research area. 3.1 Then, per research question a section is dedicated, describing its data, pre-preprocessing steps and the analysis. The critical walkability factors will be explored in section **??** through literature studies and interviews. Also a short sub-section on the average walking speed of elderly is present. Section **??** shows the data collection and pre-processing steps for the analysis of existing geo-data. The GBKA an the AHN are used. In section **??** the data collection and pre-processing steps for the collection of our own geo data, with GPS devices and an accelerometer. Eventually, the steps for analysing this data is explained in the last part of this section. The methods for combining the existing geo-data with the own collected data is explained in section **??**. With a Change Point detection algorithm, changes in the time series of the rollator walks are found, and plotted on the map to compare it to other data sources.

3.1. Study area

This project in conducted for the project MeetRollator in the scope of the recently founded Amsterdam Institute For Advanced Metropolitan Solutions (AMS). The study area of AMS in Amsterdam, see left figure 3.1 for the location. The Amsterdam Municipality contributed with data that covers the centre area of Amsterdam, indicated with the red square in the right figure 3.1. The literature study, interviews, AHN study will be mostly focussed on this area. The more general measurements were taken in Wageningen due to a more conventional location and travelling circumstances for the conducting researcher. See figure 3.10 from chapter 3.5.

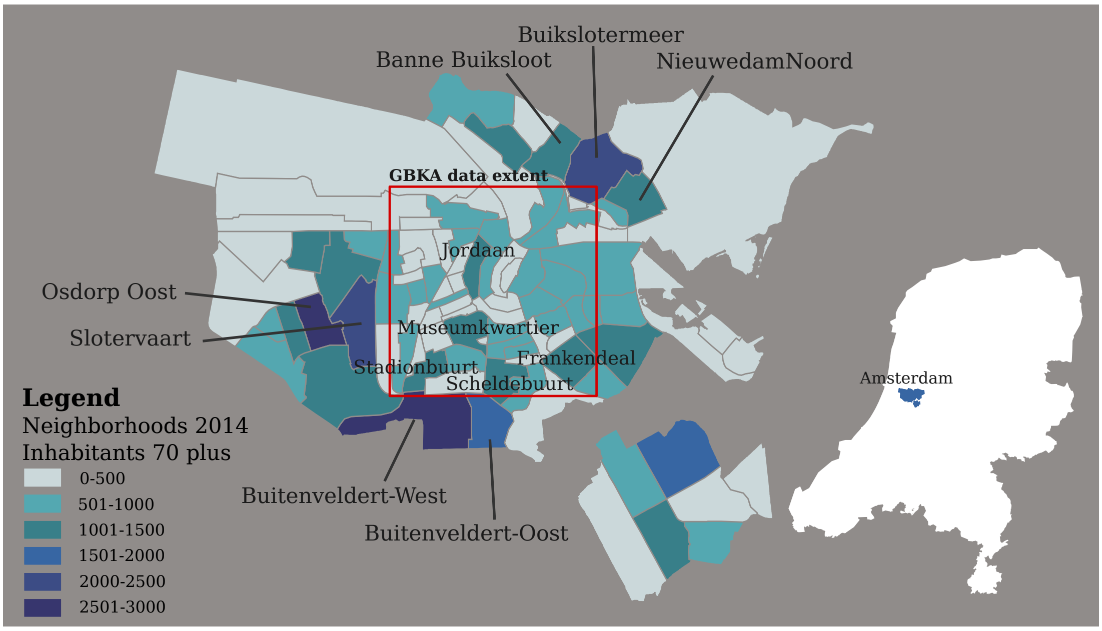


Figure 3.1.: Study area Amsterdam, The Netherlands

There is no exact information on the amount of elderly using a rollator in Amsterdam or where they live. There for the CBS statistics of 2013 were used to detect the neighbourhoods were the most elderly above 70 live. In figure 3.1 can be seen that in the centre the most elderly live in the Jordaan. In the whole of Amsterdam the most elderly can be found in the South West and North.

3.2. Method RQ 1 - Finding the critical factors for walkability

3.2.1. Literature study

From literature research, all possible problems that elderly with a rollator can encounter were gathered. Together with the extend of the problem importance. This to form the first main idea of what the possible critical factors could consist of and the eventual list of findings will be used to support and design the interviews with the elderly and finding requirements in the policy and design policies. The literature study was conducted from October 2014 until January 2015.

3.2.2. Interviews

In the initial idea was an interview that would consist of 3 parts; first a general part, about age, health and the use of the rollator. The second part is a list of possible problems the participant could encounter. The third part would be drawing on a map, where the participant walks and where certain problems occurred. See overview 3.2. Though after developing and experimenting the final form and the method of conducting changed quickly.

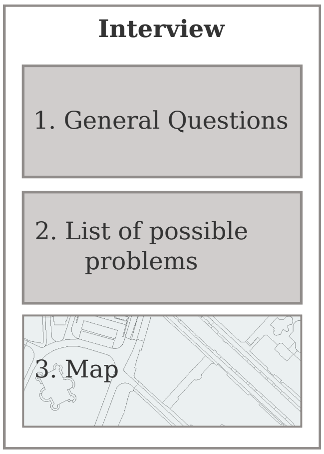


Figure 3.2.: The 3 parts of the interview

The questionnaire as shown in Annex A.4, consisting of several pages was developed. The questionnaire was tested, with the researchers grandparents. This concluded that the questionnaire is not a good form for obtaining information form elderly. The reaction of the participants was, that things were unclear and not all questions were answered. Also the amount of text scared the elderly, feeling uncomfortable with their abilities of reading and writing. Therefore, the form of the interview quickly changed to an informal chat, were the researcher used a check-list, making sure all questions were asked while chatting in random order.

The second part, containing a list of possible problems the elderly could encounter was constructed after the literature research. 5 categories are constructed:

- Quality of the pavement

- Obstacles
- Overall business
- Safety feeling
- Environmental characteristics

The total list can be found in annex A.6. For the elderly did not feel like reading too much, also this part of the questionnaire was conducted oral. Every possible problem on the list, were read out loud to the elderly and asked to rate from 1 to 5, 1 is they never encounter the problem to 5; they always encounter the problem. The conducting researcher circled the number from 1 till 5 according to the story of the participant.

The third part, drawing or pointing out problems on a map was quickly cancelled, as the elderly had difficulties reading the maps. They did, though, name streets and locations but the conducting researcher was too unfamiliar with the surroundings to translate this quickly onto the map.

Several elderly care houses were contacted as well as the neighbourhood care of Amsterdam centre. While sounding enthusiastic from the first point, it was hard to arrange appointments with elderly.

The total amount of participants for personal interviews were only 2.

Next to this, also participants on the Rollator Loop were interviewed. Around 10 people were shortly interviewed about the general problems they encounter while walking outdoors. But not the complete list.

3.2.3. Rollator Loop - Average walking speed

We visited the yearly event, the Rollator loop in Amsterdam on the 9^th of September 2015. Here we conducted interviews, measured several walks and gained overall information about the walking performances of that day.

Little information can be found on the internet about the general walking speed of elderly with a rollator. Because the opportunity was there to find out more about the average walking speed of elderly with a rollator, this was conducted as well. MySports, a company for time tracking during sport events, measured the walking time of every participant. [9] The outcome of the Rollatorloop 2015 and 2014 were used to do a small side study on walking speed per distance and gender.

3.3. Method RQ 2A - Collection and analysis of available geodata

3.3.1. Data Collection and Pre-processing - Topology

The municipality of Amsterdam, provided the GBKA (grootschalige basis kaart Amsterdam). The GBKA is the precursor of the BGT (basisregistratie grootschalige topografie) which will be used after 1 Jan 2016: the basic registration of large scale topography. The GBKA is obtained, maintained and provided by the municipality. It contains information about transport, water, buildings, street furniture, land use and public space. [1] The GBKA is delivered in file format ESRI Shape files and is projected in RDnew.

Next to this also the website amsterdamopendata.nl is consulted for extra data. [27] The data downloaded form amsterdamopendata are CSV files containing the X and Y coordinates in RDnew and WGS84. The CSV files are opened with Qgis and transformed to Shape file to work with the rest of the data.

3.3.2. Analysis - Determining pedestrian area with GBKA

The detailed GIS study will be done on the area Jordaan in Amsterdam. The Jordaan is part of the Historic Centre belt form the Puccini method. (Gordel Historische kernen) This means most pedestrian pavements and streets are made out of baked red bricks. [2] The GBKA contains polygon features for road sections. Though, these do not contain a label, indicating which purpose of use it has. See [1]. The first step will be to see if it is possible to derive the pedestrian area from available data. The Puccini method contains 6 classes for road destination [2], see the list below. Though this distinction is not used in the geo data available at the municipality.

1. Pedestrian
2. Bicycle
3. Public transport
4. Trees and street furniture
5. Cars (moving)
6. Cars (Parked)

For analysis, this research we are only interested in the pedestrian area, so the distinction between areas to walk on safely, and areas not walked on safely is made. The classes from Puccini are simplified to 3 classes, were mixed space is not taken into consideration.:

1. Transport: Cars, bikes, public transport.
2. Pedestrian area : Including square, stairs, parking places.

3. Unpaved: trees, parks, bank, garden.

First, all the road sections of all levels are merged with the bridge features and clipped to the Jordaan neighbourhood. A new column is created, class, to assign 1,2 or 3 to according to the purpose of use. Figure 3.3 shows the decision tree of steps taken to assign the three classes to the road sections. The classification process starts from the top to the bottom, in every step assigning the selected group the class and continuing with the features which do not have a class assigned yet. The first steps are done by selecting criteria on the available attributes of the road sections. After this other shape-files from the GBKA are used to derive pedestrian area and the tool selection by location is used. For example, street furniture is often placed on the pedestrian area and not on roads for moving cars. In the end, all remaining sections are assigned class 1 transport. All data is from the GBKA except the parking plots which are downloaded from www.amsterdamopendata.nl.

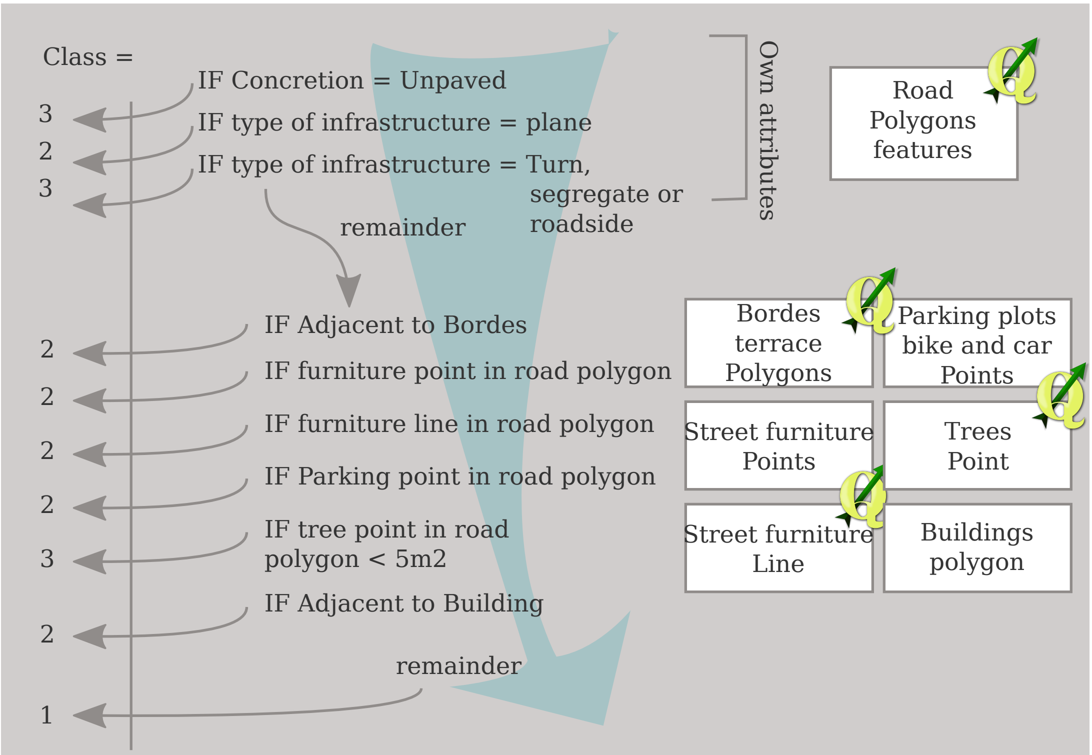


Figure 3.3.: Classification steps road sections

3.3.3. Data Collection and Pre-processing - AHN

The AHN2 tiles covering the research area were downloaded from www.nationaalgeoregister.nl. The AHN is measured with laser altimetry or LIDAR. Laser beams shot from an air plane and localized with GPS. It is measured over several time periods and merged in the end to get a detailed measurement of the height. With a measured point density of 6 to 10 point per m^2 [40]. The eventual end product delivered is corrected to ground level, so vegetation, buildings and other object do not appear. [40] These filtered areas are given no-data values. The raster data has a resolution of $0.5m^2$ and a precision of systematic and stochastic error of max $5cm$. The projection is the Dutch projected coordinate system RD new. [40] Because the AHN2 is already delivered in RD new and corrected for ground level, no or little pre-processing is needed. Apart from downloading the correct tiles and merging these together for the appropriate area.

3.3.4. Analysis - Mapping sloping surfaces with AHN data

The Policy of Amsterdam states that pedestrian areas with slopes more than 4% is perceived negative. [35] The slope is derived from the AHN2. Also per road section, the average slope is calculated. The pedestrian classification with the GBKA are used to compare road sections for transport versus pedestrian area.

First derivative - Slope

The first derivative or slope provides the degree of slope per pixel. This can be calculated with the following formula on cell to cell basis.

Degree of slope:

$$\tan\theta = \frac{rise}{run} \tag{3.1}$$

[17]

So slope in degrees:

$$\theta = \tanh \frac{\sqrt{\frac{dz}{dx}^2 + \frac{dz}{dy}^2} * 180}{\pi} \tag{3.2}$$

Source: ESRI http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=How%20Slope%20works [redacted]
[17]

3.4. Method RQ 2B - Collection geodata of rollator movements and analysis

The data collection and pre-processing per sensor used in this research will be explained in the next sections per sensor. The different sensors make use of different time zones or geographic systems, therefore some general pre-processing steps had to be conducted to standardize all the files in order to compare them in the end.

3.4.1. Data Collection - GPS

Several sensors were used for measuring GPS, varying in its details and specifications. The reason several ways to measure location were used is because not all the devices were available all the time.

Garmin Summit For the rollator loop the Garmin Summit was used with the following specifications:

- Time zone: UTM
- Projected Coordinate System: WGS84

GPS Geotracker On the smart phone the application GPS Geotracker was used. Version: 3.0.3 from 23 July 2015 Author: Ilya Bogdanovisch. This resulted in the following specifications:

- Time zone: UTM
- Projected Coordinate System: WGS84

Leica GNSS RTK For more precise location measurements the Leica system was attached to the Measurement Rollator. Though, only one Leica system was available and it was to heavy to attach to an elderly's rollator. The following specifications:

- Time zone: UTM
- Projected Coordinate System: WGS84

The Leica is much more precise then the Garmin or the GPS tracker on the smart phone. But when the Leica was not available, the other two methods still gave a good reference as were the route was.

3.4.2. Data Pre-processing - GPS

Figure 3.4 shows all pre-processing steps that are applied to all location datasets. First the files are imported into Arc-map, creating point features. From from GPX or KLM file. When necessary, they were transformed from WGS1984 to RD new. The time attribute was edited all data contained the format YYYY-mm-dd HH:MM:SS.OOO and was transformed to time zone CET. The Track Analyst tool was used for computing difference in time, speed and course between every GPS point. The settings used are:

- First to second point
- Meters, Seconds, Meter per seconds and Degrees

Eventually, the dataset were manually edited to delete the start and end points, if necessary. To exclude the waiting time before the actual walking, and the waiting at the end to turn the devices off.

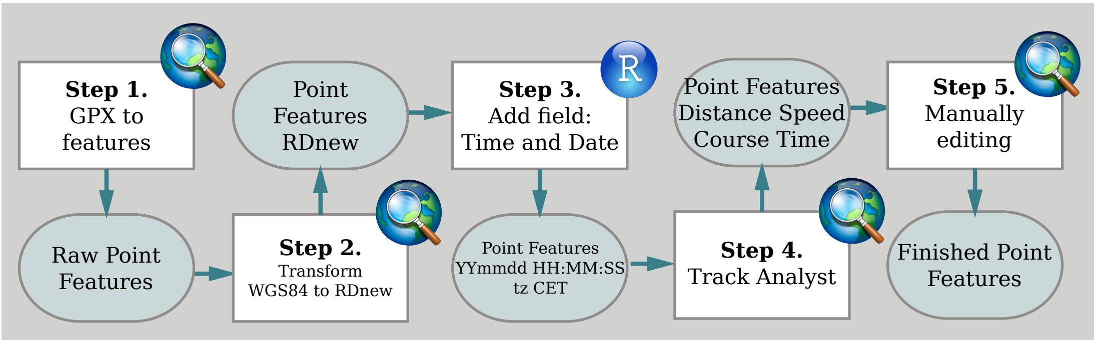


Figure 3.4.: GPS pre-processing flowchart

3.4.3. Data Collection - Accelerometer

We used a Samsung Galaxy Core GT-I8260 smart phone which was available at the conducting faculty. With the application; Accelerometer Physics toolbox accelerometer to extract the 3-axis acceleration data on the X, Y and Z axis and the total acceleration called g-force. Physics Toolbox Accelerometer proved to be the best option for extracting the data, for it is easy to use, can store the data in a csv file, with current clock time, time stamp and saves it on the local storage of the phone. It does not require a constant internet connection, and was free for use. Also no knowledge on any pre-programming to read the sensors was required. Some of the other application alternatives considered are: Accelerometer Monitor from Mobile Tools, Accelerometer Monitor from Keuwlsoft Tools, and the AcMeter. Their specifications and reasons why not used, can be found in Annex A.5.

During all measurements, the smart phone will always be placed horizontally on the Rollator. This means the z-axis is pointing down, and will correlate most with movements up and down. The x-axis will be pointing sideways and the y-axis front and back. Acceleration of walking speed will be seen in the y-axis. While turns will be seen in the x-axis. See figure 3.5.

Application version change

Several versions of the application were used, as the developer updated the app meanwhile. [1] In September 2015 version 1.2.9 was active. On September 9th the version available was

[1] Information provided by Chrystian Vieyra, developer of the Physics Toolbox Applications. In e-mail conversation 26-10-15.

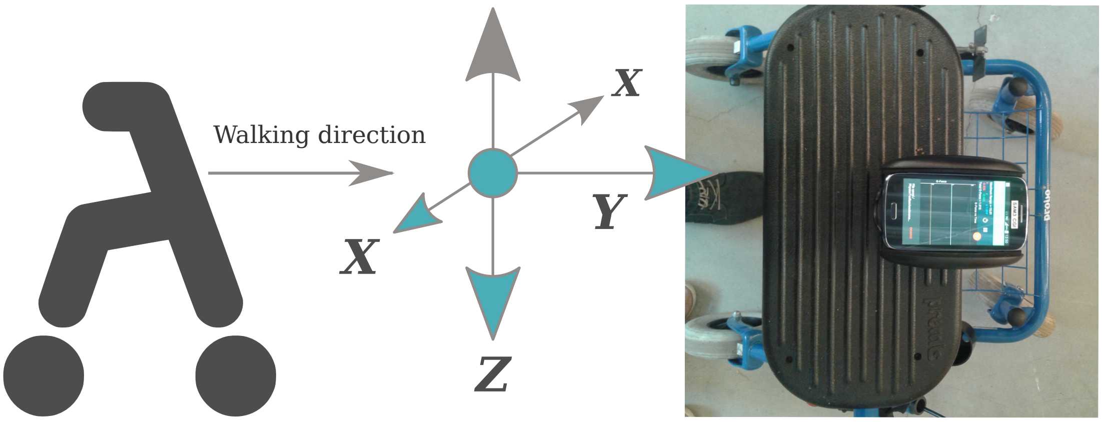


Figure 3.5.: Graphical representation of the direction of the axis of the accelerometer on the rollator.

1.3.6. Though, the smart phones used, were not always attached to the internet, and so version 1.29. was used in the beginning. This resulted into failed experiments for there was no wake lock, which keeps the device awake even if the screen turns off while the record button has been pressed. So the app was put to sleep during the measurements. Test rides on a bike were conducted but the gaps of missing data seemed to happen when large bumps occurred in the road and the conducting researcher kept the screen awake more often by touching the smart-phone more often.

Later measurements were taken with version 1.3.6 and 1.3.7, which did continue the app measuring when the screen was in sleep mode. The only difference between version 1.3.6 and 1.3.7 is a spelling mistake and the graphic layout of the record button.

3.4.4. Data Pre-processing - Accelerometer

The accelerometer dataset contains the following specifications:

- Time zone: CET. Same as the smart phone settings.
- CSV time stamp: clock time in milliseconds
- No location

The measurements resulted in dataset with per feature :

$$F_(i) = [Timestamp, A_x, A_y, A_z, A_m] \tag{3.3}$$

With A_x as the $x - axis$ acceleration A_y as the $y - axis$ acceleration A_z as the $z - axis$ acceleration and A_m as the total acceleration.

The total acceleration or g-force is supplied by the application: It is the total acceleration vector of the 3 axis combined. When tested, the calculated A_m is equal to the g-force provided by the application. It will be referred to as A_m or total acceleration, for G-force can be a confusing concept. It can be calculated by:

$$A_m = \sqrt{{A_x}^2 + {A_y}^2 + {A_z}^2} \tag{3.4}$$

For each time series A_i , with $i = x, y, z$

With cross correlation between the several features, we can detect which feature best represents the walk characteristics. A_m is a representative parameter which includes the gait acceleration (Y-axis), the vertical acceleration (Z-axis) and the lateral acceleration (X-axis). [45] By doing a cross correlation with the Z-axis and the X and Y axis a similarity between the lateral acceleration, mostly caused by the surface, and the gait acceleration is detected. The cross correlation of the x and z axis is expressed by:

$$Corr_{z,x} = \sum z(n)x(n-1) \tag{3.5}$$

Accelerometer output ranged between the normalized range of -2 to 2. Assumed is that the value of 1 means equal to 1 times the gravitational force: 9.81 m/s^2 and the value of 0 means no force pulling, so the sensor is flat. The developer stated, that these normalized values differ per type of smart phone.[2]

The application contained several settings, which were not described in the application nor on-line. Therefore some sample test were conducted to gain some basic information about the application values and settings. The application had four record interval settings, Normal, UI, Game and Fast. By placing the phone for a while on the table with the different settings the following information was found about the sample frequency of these settings:

Table 3.1.: Sample frequency of the different settings.

Setting	Points per sec (exact)	Points per sec (approx.)	Periodicity (1/(points per sec))
NORMAL	4.6	5	0.2
UI	11.9	10	0.1
GAME	49.6	50	0.02
FAST	99.4	100	0.01

This means that with an average walking speed of 1.3m/s the distance between the measured points will be, 26cm for NORMAL sample frequency, 13cm for UI, 2.6cm for GAME and 1.3cm for FAST sample frequency. For further calculations the setting NORMAL is used. This because an interval of 26 cm seams sufficient and the data set will be not too large in size to handle.

[2]Information provided by Chrystian Vieyra, developer of the Physics Toolbox Applications. In e-mail conversation 26-10-15.

Sensor errors

Because the accelerometer sensor is not calibrated and the quality is unknown, it can contain random errors (caused by the accuracy limit of the measuring instrument) or systemic error (caused by incorrect calibration of the measuring instrument). By placing the smart phone flat on a table, laying still for several hours, an indication can be given of the sensors offset. This means the z-axis is pointing down and also contains one time the gravitational force pulling it down. Resulting in numbers around 1. The x and y axis are pointing to the side and front/back. Being flat and resulting in numbers around 0.

The following sensor errors were found with setting NORMAL for every axis:

Table 3.2.: Average error per axis. Sample frequency 5 per sec (NORMAL)

SAM 3		SAM 4		SAM 5	
Average error from 0		Average error from 0		Average error from 0	
ξ_{A_x}	-0.04	ξ_{A_x}	-0.05	ξ_{A_x}	-0.03
ξ_{A_y}	0.03	ξ_{A_y}	0.06	ξ_{A_y}	0.05
ξ_{A_z}	1.01	ξ_{A_z}	1.02	ξ_{A_z}	1.03
ξ_{A_m}	1.02	ξ_{A_m}	1.02	ξ_{A_m}	1.03

These average errors ξ_{A_x} , ξ_{A_y}, ξ_{A_z} and ξ_{A_m} are extracted from all measured Accelerometer time series per smart phone.

3.4.5. Assigning location to accelerometer data with GPS

For reference, the accelerometer data can be linked to the location by using the time-stamp of the accelerometer and the GPS points. With the time stamp, the first GPS point before and the first GPS point after that time is taken. Because the time difference between the first GPS point and the unknown accelerometer point is known and the speed (s) between the GPS points, the distance(d) and so location(x, y) of the unknown accelerometer point is calculated.

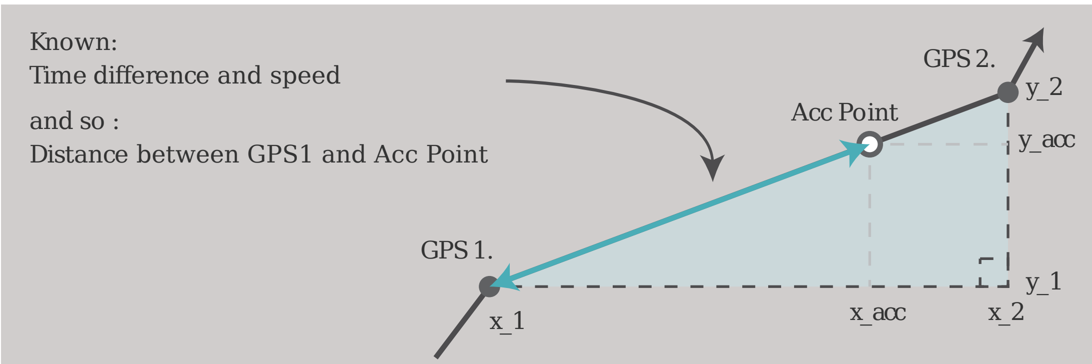


Figure 3.6.: Graphical explanation of change point location calculations

With coordinates (x_1, y_1) and (x_2, y_2) in RDnew as the known first and second GPS point, respectively.

The distance between (x_1, y_1) and (x_2, y_2) is calculated by:

$$d_{1,2} = \sqrt{(y_1 - y_2)^2 + (x_1 - x_2)^2} \tag{3.6}$$

Then, the distance between GPS point 1 (x_1, y_1) and the un-located accelerometer point (x_{Acc}, y_{Acc}) is calculated with:

$$d_{1,Acc} = s * timedifference((x_1, y_1) - (x_{Acc}, y_{Acc})) \tag{3.7}$$

The unknown x coordinate of the accelerometer point is calculated with:

$$x_{Acc} = x_1 + \frac{d_{1,cp}}{d_{1,2}} * (x_2 - x_1) \tag{3.8}$$

And the unknown y coordinate of the accelerometer point is calculated with:

$$y_{Acc} = y_1 + \frac{d_{1,cp}}{d_{1,2}} * (y_2 - y_1) \tag{3.9}$$

Now we can add the location specific data to the change points, the speed(S) extracted from the track GPS points and the AHN values, height and slope. Resulting in a feature per observation of:

$$F_(i) = [Timestamp, A_x, A_y, A_z, A_m, s, height, slope] \tag{3.10}$$

3.4.6. Data Collection - Movie material

Most walks were recorded on film, for reference aid. This was done with either a go-pro, flip camera or with the smart phone camera. Pointed at the direct surface in front of the rollator. The images are not used for calculations, solely for reference backup.

3.4.7. Analysis - Mapping irregular surfaces with an Accelerometer

Several test were conducted with the Measurement Rollator on different surfaces. To see if the vibrations of the rollator are more fierce on surfaces with a more irregular surfaces. Indicating more surface hindrance and so more energy is needed for the rollator user. The assumption is, that the vibrations caused by surface hindrance can be measured through the variance of the z-axis acceleration. We used the Accelerometer (Physics Toolbox version 1.3.7) and the Garmin to record GPS. The goal was to walk with an average walking speed of $4.7km/h(3.26.2km/h)$. This is the walking speed found from literature and own research. Though, while walking it felt quite fast. So the walking speed was kept around 4 km/h as best as possible. The researcher walked herself with the rollator over different surfaces. Each a distance of around $20m$. All the pavement surfaces structures shown in image 3.7 were tested. Asphalt or tarmac, brick paving, tiles, gravel, grass and a smooth concrete surface inside was measured.

Figure 3.7.: Image of every measured surface

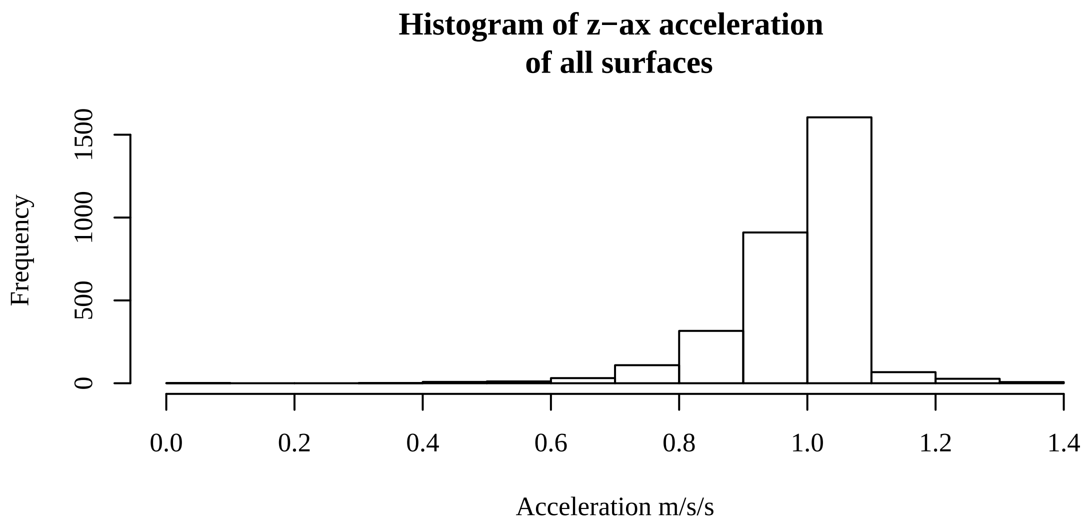


Figure 3.8.: Histogram of all surfaces z-axis acceleration

Statistics

By providing the descriptive statistics of the accelerometer output as a normal distribution, the differences in the vibrations on different surfaces can be explained. The data is approaching a normal distribution as can be seen in the example histogram of all the surfaces combined.(3.8) Vibration goes into both directions so the mean will not show a surface specific outcome and will not differ much between the different surfaces. The means calculated only gave values around the 1. See table 4.5 in the results. The variability shows better how rough the surface is. Therefore the variability is used, or the standard deviation together with the 5-number summary to create box plots. Including, the minimum, maximum, median and first and third quantile. To show a better understanding of the effect of the surface on the vibrations on the rollator. The formula for the mean variance and standard deviation:

Mean:

$$MeanA_z = \frac{\sum_{k=1}^{n} A_z}{n} \tag{3.11}$$

Variance:

$$\sigma^2 = \frac{\sum_{k=1}^{n}(A_z - mean(A_z))^2}{n-1} \tag{3.12}$$

Standard deviation:

$$\sigma = \sqrt{\frac{\sum_{k=1}^{n}(A_z - mean(A_z))^2}{n-1}} \tag{3.13}$$

Comparison with Matthews et al. (2003)

In Matthews et al. (2003) [25] a reference score for hindrance of specific surfaces is provided. Shown in table 3.3. Small test were conducted measuring surface hindrance for wheelchair users, aiming at surface type and quality for mobility. Six common urban surfaces were tested: concrete, paving, tarmac, brick, grass and gravel. A wheelchair with occupant was pushed down a small ramp the distance rolled provides an measure for rolling resistance. [25] These values will be used as a reference, to see if the measured vibrations of the Accelerometer correlate. Because the reference numbers are relative, also the measured outcome is recalculated to a relative factor. Taking the most smooth surface as factor 1 and calculating the rest of the surfaces from this. See results in figure 4.8 for a comparison of the values of Matthews and the calculated factors.

Table 3.3.: Relative hindrance scores of surfaces, low scores represent levels of least hindrance [25]

Concrete	Paving	Tarmac	Brick	Grass	Gravel
1	1.2	1.3	1.6	6	8

3.5. Method RQ 2C - Mapping abnormal or change events with change point detection using Accelerometer, GPS and AHN2 data

Assuming that in the optimal circumstances, someone will walk with a specific speed in a monotonous way and the pavement has a continues surface, the measured acceleration in the z-axis will show a continuous pattern. An *abnormal* peak in the continuous data will indicate a problem or obstacle in the pavement surface. Next to this, a sudden change in the walking speed of the person, could indicate a disturbance of the walking route. Together, a sudden drop in speed, plus a peak in the z-axis acceleration, could indicate big bumb or obstacle which causes a change in the walking behaviour of the pedestrian. For example, tackling a curb obstacle with the rollator.

By looking at the changes or anomalies in the time series data of speed, slope and z-axis acceleration measured during a walk and linking them to location trough GPS measurements, the physical obstacles or hindrances can be located. The changes or anomalies in time-serie data can be determined by the change-point package of R containing specialized change-point finding algorithms for detecting multiple change-points within data and a variety of test statistics. [22, 21] A change point is the estimation of the point at which the statistical properties(mean or variance) of a sequence of observations changes.

3.5.1. The changepoint package

The ChangePoint package of Killick et al. 2014 contains functions to detect multiple changes in the mean or the variance of large datasets. First we will explain the concept of change-points and the segment in between. Then, the methods offered by the package will be explained and the possibility to choose different statistical models for penalty fitting. The exact approach of identifying multiple change-points, formulas, methods and references can be found in the report of the changepoint package by Killick et al. 2014 [21]

Having an ordered sequence of data $y_{1:n} = (y_1, ..., y_n)$, a change-point is said to occur within this set when there exists a time, $1, ..., n1$, such that the statistical properties of segment $y_1, ..., y$ and segment $y_{+1}, ..., y_n$ are different in some way. Consequently the m change-points will split the data into $m + 1$ segments, with the i^th segment containing data $y_{(_{i1}+1):_i}$. Each segment will be summarized by a set of parameters. [21] Possible is to use the two sides: the change-points $CP_{1:m} = (CP_1, ..., CP_m)$ themselves and the segments $y_{(CP_{i1}+1):CP_i}$ between the change-points. Each, with its own set of parameters. The average variance or mean of the segment indicates the homogeneous characteristics of the dataset, between the change-points.

The Changepoint package implements three multiple change-point algorithms; Binary Segmentation(BS), Segment Neighbourhoods(SN) and the Pruned Exact Linear Time(PELT). Binary Segmentation is an approximate algorithm and most widely used search method. Segment Neighbourhoods has a long computation time but is more exact. PELT is computationally fast and exact. The number of change-points increases linearly as the data set increases. All the different change point detection methods and penalty values had to be tested to see which model approaches the most plausible result and approaches the truth the best. This was shortly done for all individual dataset. Also the best possible penalty settings are considered, for there can be a big difference in characteristics of the dataset for speed, slope and acceleration.

The penalty settings are used to prevent the model for over fitting. Several statistical models are available, BIC, AIC or Hanan-Quinn. The penalty settings can discourage over fitting and increases the number of parameters in the model to almost always improve the goodness of fit. When over or under-fitting occurs, we adjusted the penalty. Especially in the speed and slope datasets, over-fitting was a problem. Extreme peaks or graduated steps in the speed are due to measurement errors in the GPS. If a model fits too well, these are taken as truth, the penalty settings can even out those extreme measurements. Most often the penalty was set to $1.5 * log(n)$.

3.5.2. Routes measured

For testing if the change-point method is usable for detecting obstacles while walking, several test were walked, during the RollatorLoop 2015. We used the Garmin Summit for the participants and the Leica system on the Meetrollator. 3 smart phones with the Accelerometer (Physics Toolbox version 1.2.9 were used. Here all the accelerometer measurements failed because or the wrong application version. See Annex A.7 for the measured tracks and the accelerometer output. Eventually, the failed measurement with the Leica system, could be used for analysing speed and slope. But the accelerometer was left out here. Also, half way the route, the Leica system stopped walking. Therefor only half of the route was measured. See figure3.9 for the route. So, secondly a bike ride was monitored for testing the application settings again, with the Accelerometer (Physics Toolbox version 1.3.7) and the GPS Geotracker Application to record GPS. When this seemed to work, also a walk with the measurement rollator was conducted by the researcher herself. Using the Accelerometer (Physics Toolbox version 1.3.7) and the Garmin Summit. Both tracks are shown in figure 3.10.

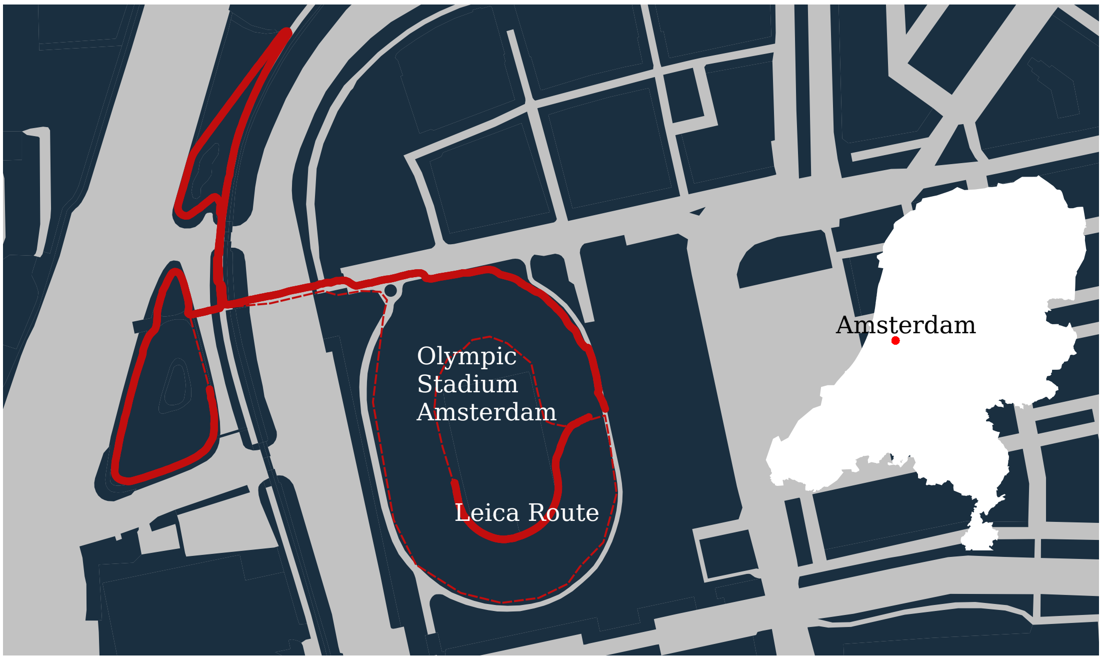


Figure 3.9.: Map of Leica route in Amsterdam

The datasets of the accelerometer are combined with the location dataset of the GPS measurements. The location assigning is done with the same method as described in the previous section **??**. Also here the location specific data was added to the dataset, the speed(S) extracted from the track GPS points and the AHN values, height and slope. Resulting in a feature per observation of:

$$F_(i) = [Timestamp, A_x, A_y, A_z, A_m, s, height, slope] \tag{3.14}$$

The dataset per route was approached as a time-series dataset to applying the change point method. Each route and data range on the route had its own specific settings to get the best model of fit. Eventually this resulted in a change point feature for every $m^(th)$ change point observation:

$$CP_m = [breakpointindex, mean, variance, time, x, y] \tag{3.15}$$

This is applicable to the acceleration, speed, slope and height. The change-points are detected with the variance setting for the acceleration and mean for change-points detection for speed, height and slope:

$CP_{mean(s)}, CP_{Var(A_z)}, CP_{Var(A_m)}$ and $CP_{meanHeight}, CP_{meanslope}$

With all change-points having location coordinates(x, y) in RD new and a time stamp. When plotting all change points on the map, visually, patterns in the route can be detected.

Figure 3.10.: Map of tracks measured in Wageningen

4. Results

4.1. Results RQ 1. - Finding the critical factors for walkability

4.1.1. Findings critical factors from literature

Table 4.1 shows a summary of the occurrence of the amount a certain criteria is found in literature, per category and level. The criteria are counted double if found multiple in different literature pieces. As can be seen in the table, most reports mentioned criteria that can be found on pavement level and criteria falling into the category of route attractiveness.

Table 4.1.: Overview of finding in literature research

		Level					Total per category
		Crossing	*Pavement*	*Street*	*Environment*	*Wheather*	
Category	*Accesibility*	9	20	3	8	0	**40**
	Quality	4	**24**	6	0	0	**34**
	Obstructions	0	20	0	0	0	**20**
	Route Atrractiveness	0	7	17	21	11	**56**
	Safety	8	0	19	4	0	**31**
Total per level		**21**	**71**	**45**	**33**	**11**	**181**

In the next table, a more detailed overview of the criteria found on pavement level is given. For criteria about the pavement and objects in the way, even a more detailed criteria list is given and the amount of literature studies mentioning them. Two criteria are mentioned most, irregular surfaces and (wrongly) parked bikes and cars.

Table 4.2.: Detailed overview of criteria at pavement level

Pavement level

Sub-categories	**Count**	*Detailed criteria*	*Count*
Criteria about the Pavement (availability and quality)	**22**	Presence of pavement	4
		too wide or narrow pavement	3
		Irregular surface	**13**
		Slope	2
		total	*22*
Criteria about Curbs and Ramps	12		
Stairs precense and quality	10		
Objects in the way	**20**	*Detailed criteria*	*Count*
		Parked bikes, cars, scooters (temporary)	**8**
		Physical stationary objects (poles trees)	5
		Pavement objects(gutters)	3
		Temporary objects (commercial signs, branches)	4
		total	*20*
Unatractive objects litter poop garbage graf ty	7		
Total	**71**		

4.1.2. Summary personal interviews

Participant 1. Uses a wheeled walker already for 8 years. Without she loses balance, really depended on the rollator. Though short distances often without, but would be safer with. Although she has severe fright of falling, she walks outside at least once a day, half an hour. This to stay fit, but she would rather stay at home. When she gets tired, her ankles weaken and she is even more afraid of falling. For her, if the pavements would be more smooth, I would be able to walk much further because it is more easy and she would not get tired that quickly. Loose tiles, pits, wrongly parked cars, tourists, sloping pavements are a problem to her. Especially the amount of people on the street, she tries to avoid. In conclusion, walking is not a relaxing activity for her, she goes out, because she wants to move to stay fit. Smooth surface to walk on would increase her ability to walk and she would be able to walk more easily and further. The business on the streets is not her thing and the purposely avoids this.

Participant 2. Participant 2 is a real outdoor walker. She goes out on the streets several times a day and strolls around the whole neighbourhood. She uses the rollator for .. years and feels that the rollator is really easy and a blessing for her. It keeps her mobile and enjoy Amsterdam around her. Problems mentioned by her are the uneven tiles or half loose tiles. So not well maintained pavements. Also when cars are parked wrongly and this makes her move off the high curbs is difficult. She mentioned that the resting benches are way too low. So if she would sit on these she has difficulty getting up again. She was really positive about the people on the street, in her perception they are friendly and helpful. Also she attached a bell on her rollator, so that if someone is in the way she would just ring the bell and she can pass.

Conclusion. Most often named:

- Irregular surfaces as in Loose tiles or bad maintenance.
- Sloping surfaces
- Wrongly parked cars

4.1.3. Summary interviews at Rollator Loop

The age of the participants ranged from 77 to 94. Some used the rollator for more than 6 years, while others only since half a year. When starting using a rollator, participants said they did not dare to walk without it any more, because of fear of falling. Most of them mentioned grocery shopping as the main activity for using a rollator outdoors. Noticing the bad quality of the streets only occurs to you when your mobility worsens and you start needing a rollator to help you. Problems mentioned were; roots of trees make the pavement uneven, pavements are convex and these sloping circumstances need you to adjust the rollator all the time. The maintenance is not sufficient. Not nicely finished pavements, transition from tiles to asphalt not even. Public transport stops not adjusted. Tram rails. On the positive side, there is enough space to walk. Not all participants have difficulty with going on and off the pavement. One participant did not have any problems while walking on the street while walking to the grocery store across the street a few times per week. Sloping pavements and bad maintenance as in uneven surface, were mentioned several times.

4.1.4. Findings Amsterdam policy and summary interview municipality

More post placed and raised pavements, to avoid cars on the pavement. Public transport stops are raised for easier entrance into the bus and trams. Puccini method as design policy for public space. GIS data available but not sure what. Centre, tourist are the main problem. More ageing. Accessibility is getting a problem. Living independent is policy. There is still a lack at the municipality in providing facilities and care. Mostly focus on accessibility of public transport and public buildings. More people walk. Putting up a new framework for pedestrians. First stage to be completed end of 2015. The framework includes the design policy for public space with design principals, assumptions, guidelines, goals, tests, and products. Integrated pedestrian policy, covering all from crowd management to accessibility. Indicators should be, measurable so quantitative but also qualitative. Goal is to grow, more space for pedestrians, more use of the public space. Before the policy was scattered, now focus on one pedestrian policy.

The Puccini Method states that the side-walks are often the residual area that remains after the design of the road. [2]

Altijd een minimale vrije doorgangsbreedte noodzakelijk van 1,50 meter; - In door voetgangers druk gebruikte stadsstraten een minimale vrije doorgangsbreedte noodzakelijk van 2,50 meter. 14In de praktijk is er veel extra ruimte nodig om alle meubilair en objecten te plaatsen. Zodoende moet er bij de minimale breedtes: - 0,5 meter extra worden opgesteld ten behoeve van een slimme strook waarin parkeermeters, lantarenpalen, banken, papierbakken etc. kunnen worden opgenomen; - Indien nodig n meter extra worden opgeteld ten behoeve van uitstallingen van winkels aan de gevelzijde; - Indien nodig 1,80 meter extra worden opgeteld indien er fietsenrekken op het trottoir staan.

Trottoirbreedte en -helling Voor voetgangers, gehandicapten, met name rolstoelers en lopende gehandicapten met begeleider geldt een gewenste obstakelvrije loopruimte van 2,00m (op grond van landelijke norm minimaal 1,80m). De gewenste maat is verder afhankelijk van de intensiteiten, functies, etc 1 . Naast deze maat dient rekening te worden gehouden met extra ruimte van circa 1,00m (minimaal 0,75m) aan beide zijden van het trottoir ten behoeve van objecten zoals verkeers- borden, brandweerkranen, elektriciteitskasten, lantaarnpalen, reclame- en informatiezuilen, hekken, planten, geparkeerde fietsen, etc. De extra trottoirbreedte moet voldoende zijn om de vrije loopruimte van minimaal 1,50m te waarborgen. De toe te passen helling mag met het oog op gebruik door gehandicapten niet steiler zijn dan 1: 25 (4Voor een boomstrook op het trottoir dient minimaal 2,00m aangehouden te worden. Deze strook kan dan tevens gebruikt worden voor het plaatsen van diverse objecten en straatmeubi- lair, maar ook voor inpassing van laad- en loshavens of parkeervakken. [35]

4.1.5. Final list critical factors

The top 3 critical factors derived from all of the above are:

1. Wrongly parked bikes and cars
2. Sloping pavement
3. Irregular pavement

The first item will not be examined, for parked bikes and cars are temporary obstacles which can be hard to detect through stationary geo data. The applicability of Geo information systems for monitoring wrongly parked bikes and cars is a whole new study on its own.

The sloping pavements will be examined with available height data(AHN2). The irregular pavement will be examined trough accelerometer measurements of the rollator movements.

4.1.6. Average walking speed

The average walking speed found was $4.62 km/h$. In the table 4.3 and figure 4.1, clearly can be seen that the average walking speed decreases when walking longer distances. The total number contains all participants labelled as male, female or unknown. Therefore, the sum of male and female differences from the total number.

Figure 4.1.: Average waling speed, participants Rollator loop 2014 and 2015

Table 4.3.: Average walking speed, participants Rollator loop 2014 and 2015

Distance	Sex	Count	m/s	km/h
400	Male	25	1.56	5.60
400	Female	97	1.73	6.23
1000	Male	5	1.51	5.42
1000	Female	28	1.31	4.72
2500	Male	1	0.63	2.26
2500	Female	7	0.91	3.29
	Total	179	1.30	4.62

4.2. Results RQ 2A - Collection and analysis of available geodata

4.2.1. Determining pedestrian area with the GBKA

The GBKA was used to determine how much surface is determined for pedestrians. In annex ?? the total area of the Jordaan is shown. Here, some detailed maps shows some areas where the classification turned out to be okay, but also contains some streets which area wrongly assigned pedestrian area. In total the Jordaan has around $300000m^2$ of public road surfaces. About 53% of this is intended for pedestrians according to the developed approach. This share of road does contain poles, lanterns, bicycle racks, parking plots and all other street furniture.

Table 4.4.: Statistics pedestrian area

Road Section	Total Area	Percentage
All Road Sections	293317.25	100.00
1. Transport	133789.66	45.61
2. Pedestrians	156159.49	53.24
3. Unpaved	3368.1	1.15
Below 4% slope	114341.08	38.98
Pedestrian below 4% slope	24466.67	8.34

Figure 4.2 shows in white, the pedestrian area as approached. The Tweede Boomdwarsstraat is wrongly classified. Also bridges are mostly wrongly classified. The parking plots in the centre of the road Westerstraat are classified as pedestrian area but are not suitable for pedestrians, as it is full with cars and other street furniture. See Figure 4.3 image from Google street view of the Westerstraat.

Figure 4.2.: Detail Jordaan Road Section classification

Figure 4.3.: Google Street View image of the Westerstraat

4.2.2. Mapping sloping surfaces with AHN data

In table 4.4 from the previous section, also the area pedestrian area below 4% of slope and the total area below 4%slope is given. Consecutively, 8% and 39% of the total area. In figure 4.4 the Westerstraat can be seen, with the slope below 4% in green. The roads destined for cars are shown more general green except for the speed bumps which can be clearly distinguished. The pedestrian area on the other hand, shows more red spots. When looking at the average slope per road section polygon, also the car area (1.) stays below the 4% while the pedestrian area has higher slopes. Figure 4.5. The original hight map of the AHN2 can be found in Annex A.9.

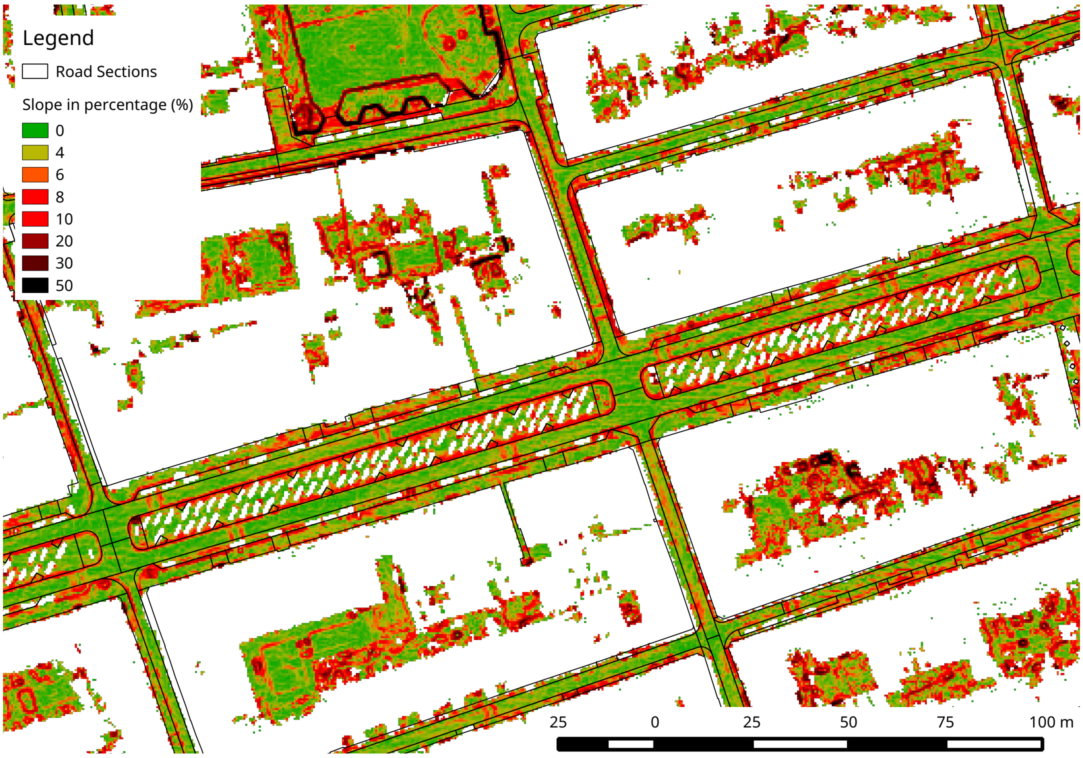


Figure 4.4.: Detail Jordaan Slope map

Figure 4.5.: Detail Jordaan Average Slope per road section

4.3. Results RQ 2B- Collection of geodata of rollator movements and analysis

4.3.1. Mapping irregular surfaces with an Accelerometer

Figure 4.6 shows the accelerometer output of the z-axis per measured surface. The exact statistical summary of every surface is given in table 4.5. Containing the total acceleration mean, standard deviation, the variance, the minimum and maximum, first and third quantile and the median. The median and mean are roughly the same for every surface, because the accelerometer measures acceleration in the vertical direction around $1m/s/s$, which is equal to gravity. Any acceleration aiming up, will also go down. The extent of acceleration a surface causes in the vertical direction, or the standard deviation or variance, tells more about the differences in surface. To show more visually the differences in variance per surface, the box plots 4.7 show spreading per surface. Clearly the difference per surface can be seen. The smooth concrete inside, gave almost no acceleration in the vertical direction, while stones or grass showed more vibration and so higher and lower values in minimum and maximum as well as the standard deviation and variance.

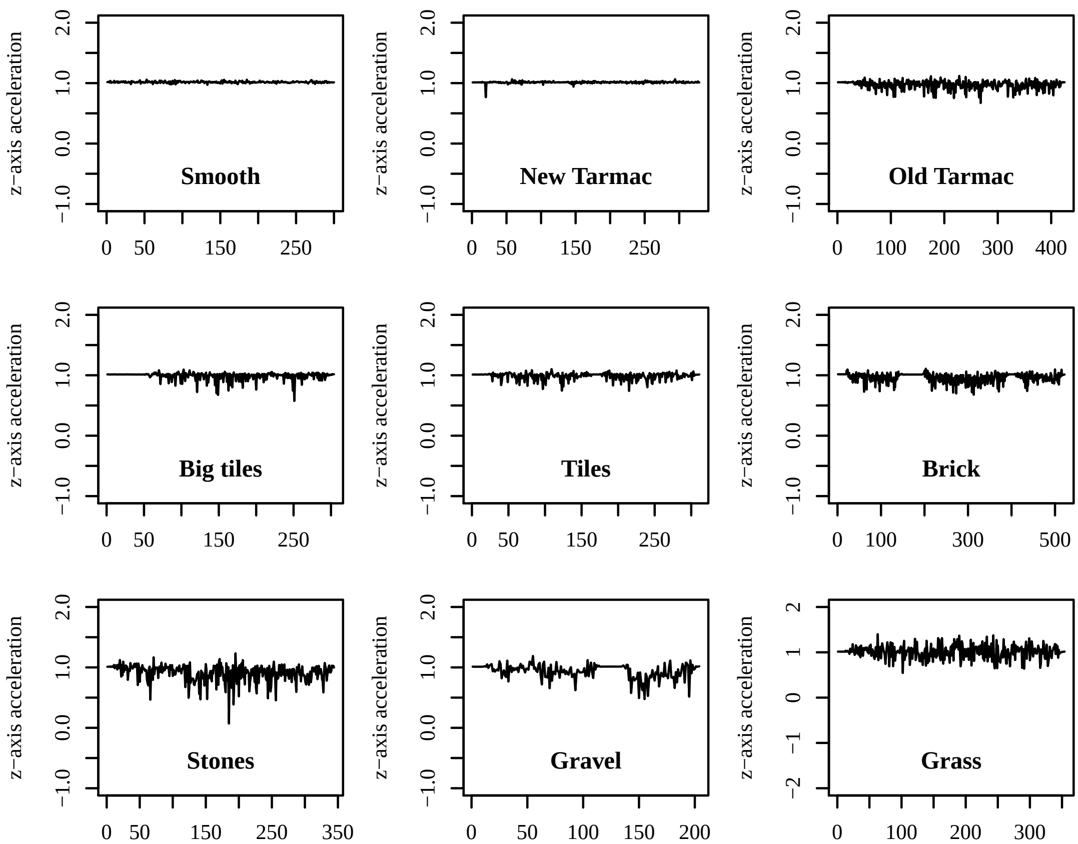


Figure 4.6.: Accelerometer data per surface

Table 4.5.: Statistic summary surface hindrance

Surface:	Mean	Std dev	Variance	[redacted]		Median	[redacted]	
Smooth	1.02	0.02	0.00	0.97	1.02	1.06	1.01	1.03
New tarmac	1.01	0.02	0.00	0.77	1.01	1.06	1.01	1.02
Old tarmac	0.97	0.07	0.01	0.67	0.99	1.12	0.94	1.02
Big tiles	0.99	0.07	0.00	0.58	1.01	1.10	0.98	1.02
Tiles	0.99	0.06	0.00	0.74	1.01	1.10	0.97	1.02
Brick	0.96	0.07	0.01	0.68	0.98	1.11	0.92	1.01
Stones	0.91	0.14	0.02	0.07	0.94	1.23	0.84	1.01
Gravel	0.94	0.12	0.02	0.48	0.97	1.19	0.87	1.01
Grass	1.01	0.15	0.02	0.54	1.02	1.40	0.93	1.10

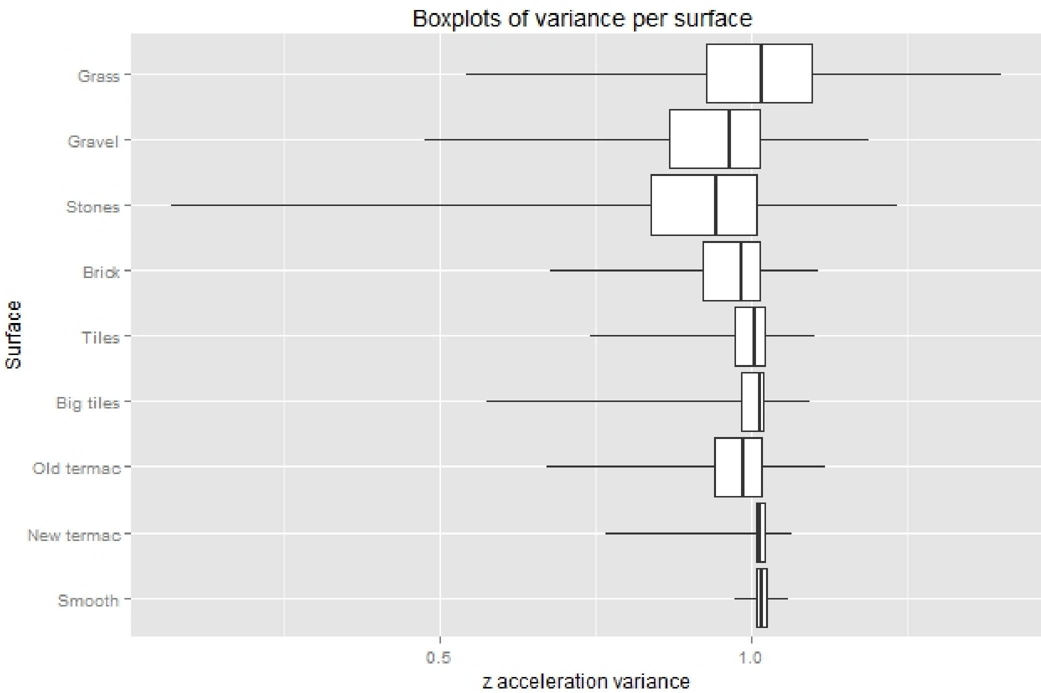


Figure 4.7.: Box plot surface hindrance variance per surface

4.3.2. Comparison with Matthews et al. 2003

From the standard deviation relative scores are assigned. Taking the smooth surfaces as basis value 1. The other values are calculated as a factor from this. Lower scores represent levels of least hindrance while higher scores represent high levels of vibration and so more hindrance. These factors are compared against the factors found in Matthews et al.(2003) and matched upon the surface description. The factors form Matthews do differ in value but are also calculated relatively to its most smooth surface, concrete. When plotting both values against each other a correlation coefficient of 0.72 is found. Indicating a positive and high correlation between the two data sets.

Table 4.6.: Relative scores of surface hindrance. Measured and Matthews

Surface	Standard Deviation of z-ax	Percentage	Factor	Factor given by Matthews	Surface name by Matthews
Smooth	0.01	100.00	1.0	1	Concrete
New tarmac	0.02	132.72	1.3		
Old tarmac	0.07	489.01	4.9	1.3	Tarmac
Big tiles	0.07	467.30	4.7		
Tiles	0.06	404.02	4.0	1.2	Paving
Brick	0.07	510.27	5.1	1.6	Brick
Stones	0.14	1000.62	10.0		
Gravel	0.12	857.41	8.6	8	Gravel
Grass	0.15	1037.63	10.4	6	Grass

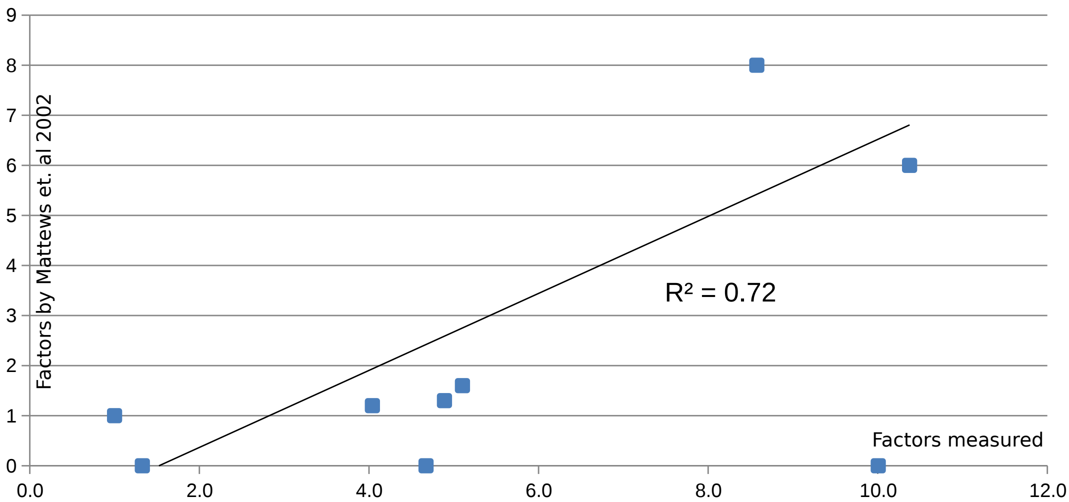


Figure 4.8.: Comparison factors measured and factors given by Matthews et al. 2003

4.4. Results RQ 2C - Mapping abnormal or change events with Accelerometer, GPS and AHN2 data

4.4.1. Comparing different Change Point detection methods

First the different changepoint detection methods and penalty values had to be tested to see which model approaches the most plausible result and approaches the truth the best. This was shortly done for all datasets, here we will show possibilities of the acceleration output of the $z - ax$ of the rollator route in detail. See figure 4.9 Walking with a speed of around $4km/h$, the distance between each measured point is around $25cm$ with a sample frequency of 5 points per second (Normal settings). The total route was 500 meter.

The first method, finding change points for the variance with PELT method, resulted in 10 change points. So on average one change point per 100 meter. Some outlying peeks are missed by the model, and are not enclosed by changepoints, while they could indicate an unevenness in the surface.

The second method variance with PELT $1.5 * log(n)$ resulted in 69 points. On average one point per 7 meter. Now, the outlying peaks are enclosed by two changepoints, indicating exactly where a abnormality happens. Changing the penalty value solves the problem of over-fitting the model. The penalty increased the number of parameters in the model and almost always improves the goodness of fit.

Method BinSeg and BinSeg $1.5 * log(n)$ took a longer computing time and resulted in only 5 change points for the variance. Method PELT and PELT $1.5 * log(n)$ for the mean resulted in no change points. Method SEGNeigh on the mean of the variance didn't gave any output. The PELT method for both the mean and variance at the same time had 50 change points.

Eventually, for detecting changepoints in the variance of the acceleration the PELT method with a manual pen value of $1.5*log(n)$ is used to overcome over and under fitting. For it showed the most plausible result.

A same kind of figure for the analysis of the best methods to detect changepoints in the speed dataset, can be found in annex A.10. For the speed we look at changes in the mean.

Significant changes are, that the speed drops 2 times almost to the zero, the first drop is waling up and down the pavement curb. The second drop is a curve in the road where probably a short stop was made.

The first method, finding change points for the mean with PELT method, resulted in 3 change points and missed the second drop in speed. The second method variance with PELT $1.5*log(n)$ resulted in more points and did detect the second drop in speed. Plus, broke up the first stop into 3 parts. Method BinSeg, BinSeg $1.5 * log(n)$ and SEGNeigh resulted in no output.The PELT method for both the mean and variance at the same time had made a break point on every value of a change in speed, so over-fitted the model. When looking at the change points in the variance, PELT and PELT $1.5 * log(n)$, more change points are detected, sometimes giving a logical breakpoint, for example at the huge drop in speed. But also multiple points really close to each other are detected, singling out steps in gradually decrease or increase in speed over a longer distance. Which gives too many points, as every 5 meter.

For every individual dataset, the best possible penalty settings are considered, for there can be a big difference in characteristics of the dataset for speed, slope and acceleration. Though, for all datasets, the PELT method was used, because it has less computing time but has a good accuracy and distribution of change points over the dataset. In general the slope datasets resulted in too much over-fitting, therefore a different penalty type was chose, the AIC or the BIC model. For every dataset the model of fit is indicated in the summary tables of the next section.

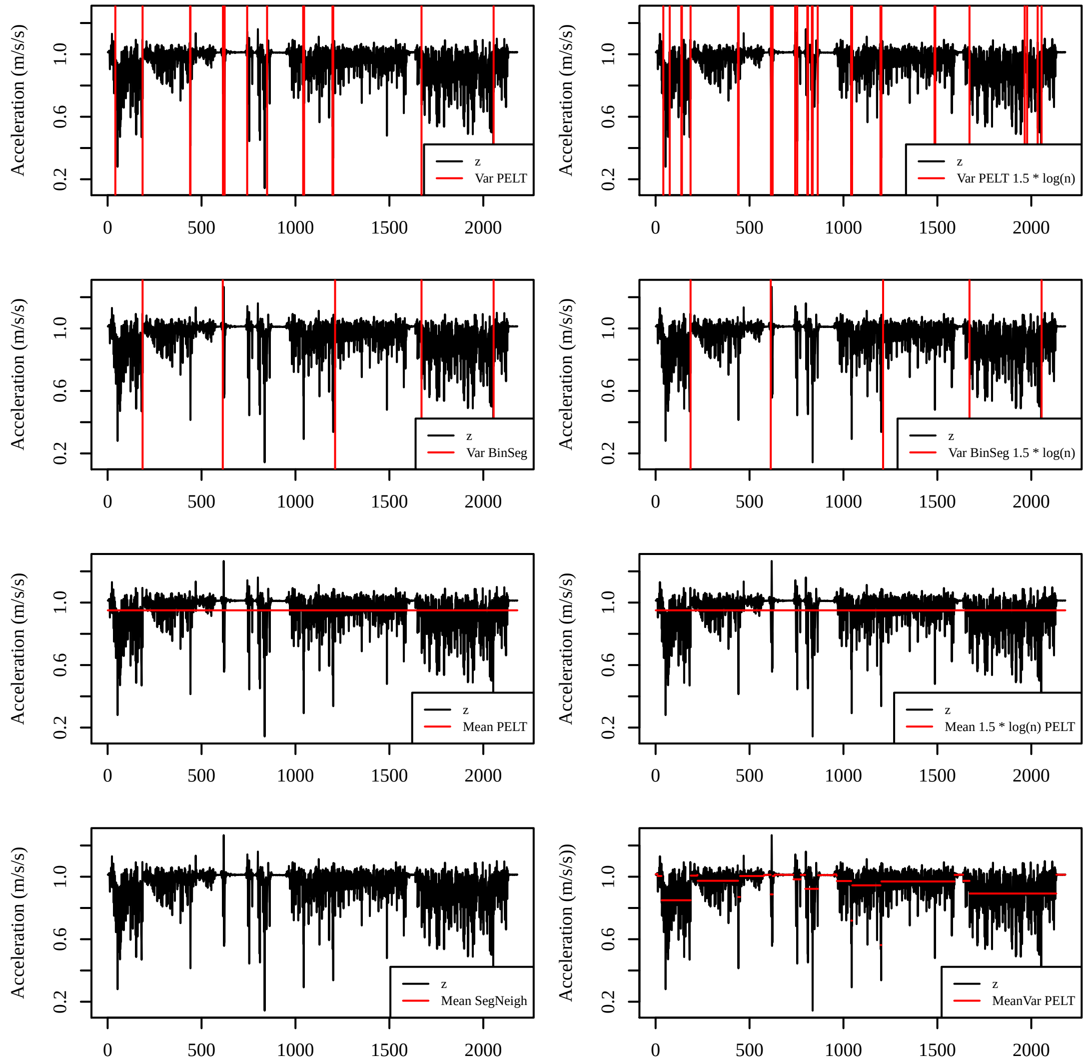


Figure 4.9.: Comparison different algorithms for change point detection in accelerometer z-axis output

The next sections show the change points detected for average height, average speed, average slope, and variance of the total acceleration for all the measured routes. The change points are assigned a location through linking its time stamp with the time of the GPS data.

4.4.2. Change point and Segments found for the Meetrollator walking route

In figure 4.10 the route of the measurement rollator is shown with the detected change points indicated. The numbers show the time index which is the same as found in the graph 4.12, which shows the datasets with the changepoints and segments. The average walking speed was $1.2m/s$.

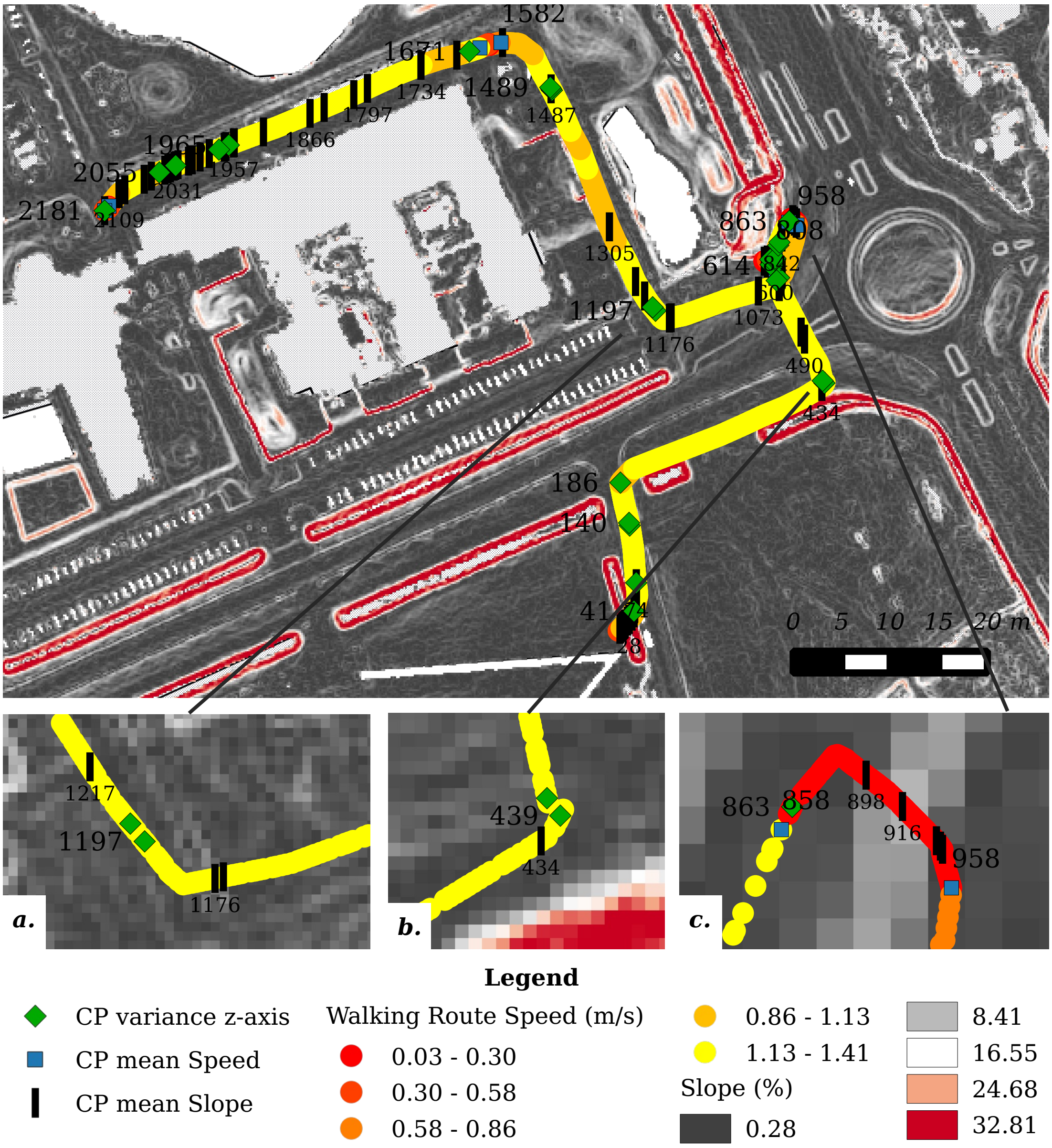


Figure 4.10.: Change points for the Meet Rollator route

The right zoomed in square shows the area where a little detour was taken, walking down and up the curb again. The slope map clearly shows the location of the curb and the pavement. Specifically in the top, the crosses show a decrease and increase in speed while going over the curb. The red dots show a change in slope where the curb is located. Only no change in variance is detected. The left zoomed in square shows again that the change point in slope is detected, where the little red dots and the slope map show a bump. Though the change point in the accelerometer fall slightly later in the route. The slope is derived from the location of the track, while the accelerometer is linked to the time stamp of the GPS. Because of GPS inaccuracy's these points do not have to fall at the same point in the route.

Figure 4.11.: Example surface of Detail B. from figure 4.10

Table 4.7.: Summary of changepoint output and methods used, per dataset, for the MeetRollator walking route

	Slope	Speed	Variance z-axis	Variance total acceleration
Changepoint type	Change in mean	Change in mean	Change in variance	Change in variance
Method of analysis	PELT	PELT	PELT	PELT
Test Statistic	Normal	Normal	Normal	Normal
Type of penalty	Manual with value 11.53131	Manual with value 11.53131	Manual with value 11.53131	MBIC with value 23.06262
Minimum Segment Length	1	1	2	2
Maximum no. of cpts	Inf	Inf	Inf	Inf
Number of changepoints	69	7	28	12
Created Using changepoint version 2.2				

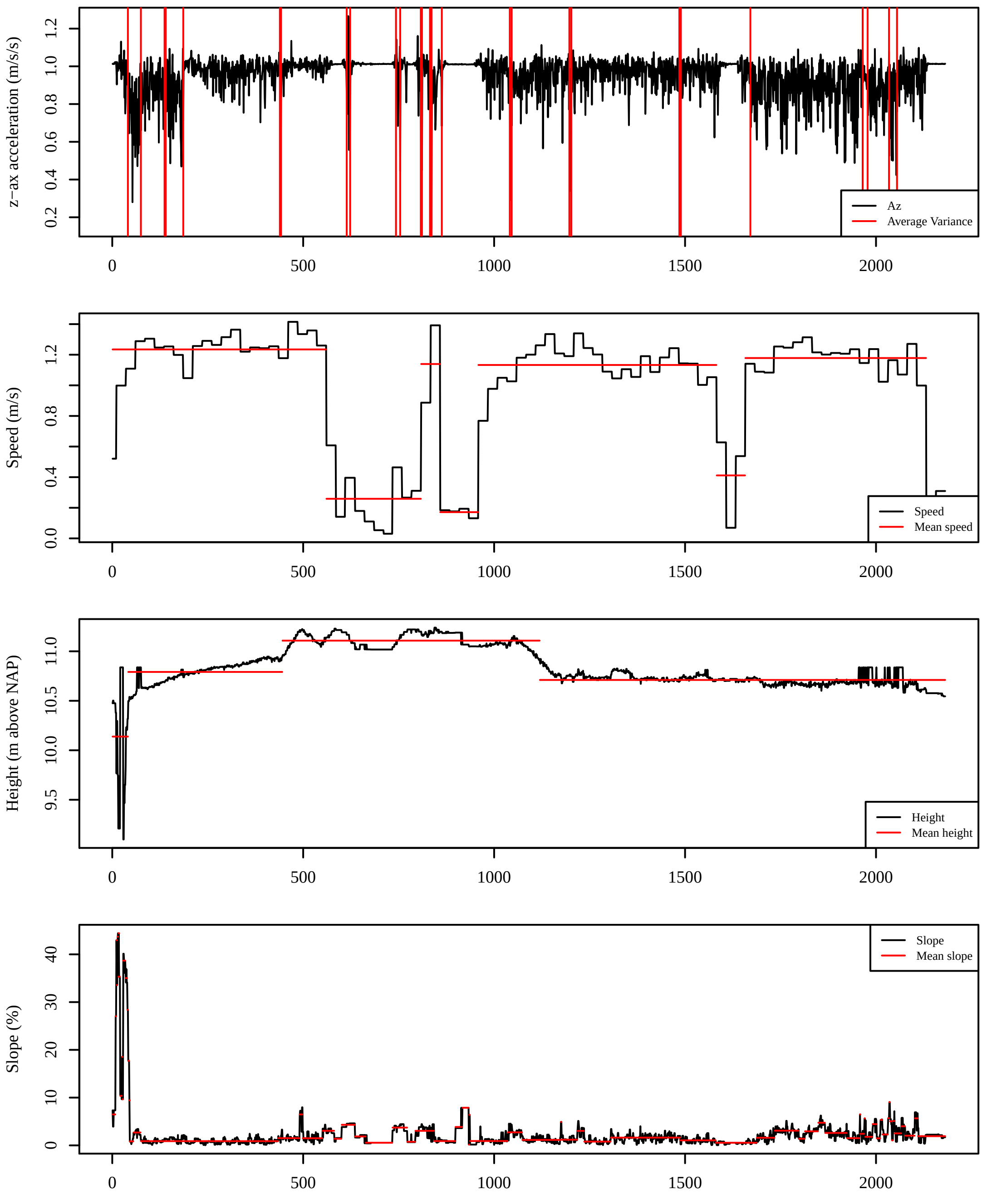


Figure 4.12.: Change point segments, per dataset, for the MeetRollator route

4.4.3. Change point and Segments found for the Leica walking route (without accelerometer)

From the failed measurements, there was on route walked with a Leica system. Though, there are no accelerometer measurements on this route, the location is more accurate and the comparison with the slope and speed could give better results.

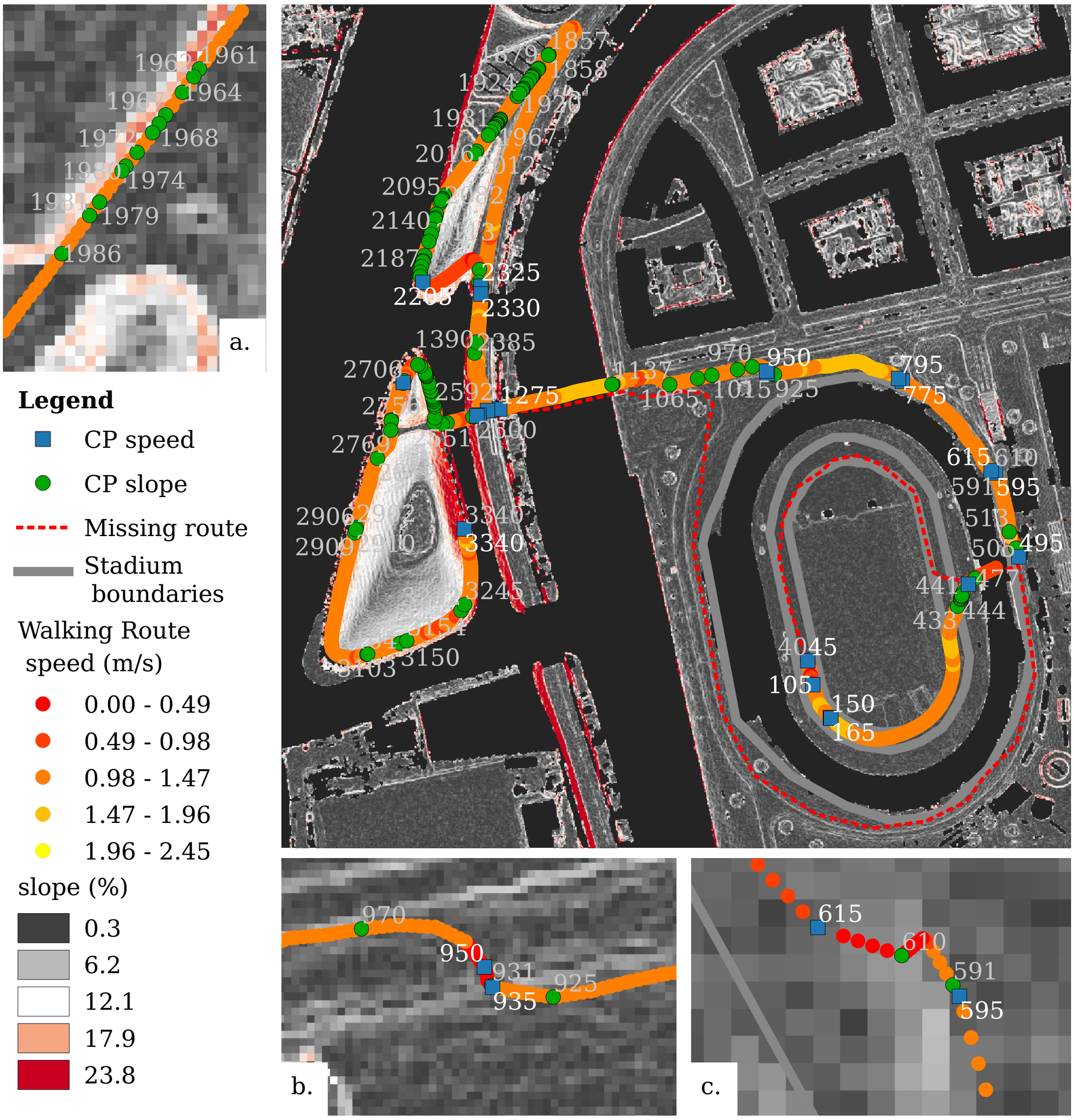


Figure 4.13.: Change points in speed and slope for the Leica route on the map

Table 4.8.: summary change point methods for Leica

..	Slope	Speed
Change point type	Change in mean	Change in mean
Method of analysis	PELT	PELT
Test Statistic	Normal	Normal
Type of penalty	MBIC with value, 24.34118	AIC with value, 4
Minimum Segment Length	1	1
Maximum no. of cpts	Inf	Inf
Number of changepoints	123	20
Created Using changepoint version 2.2		

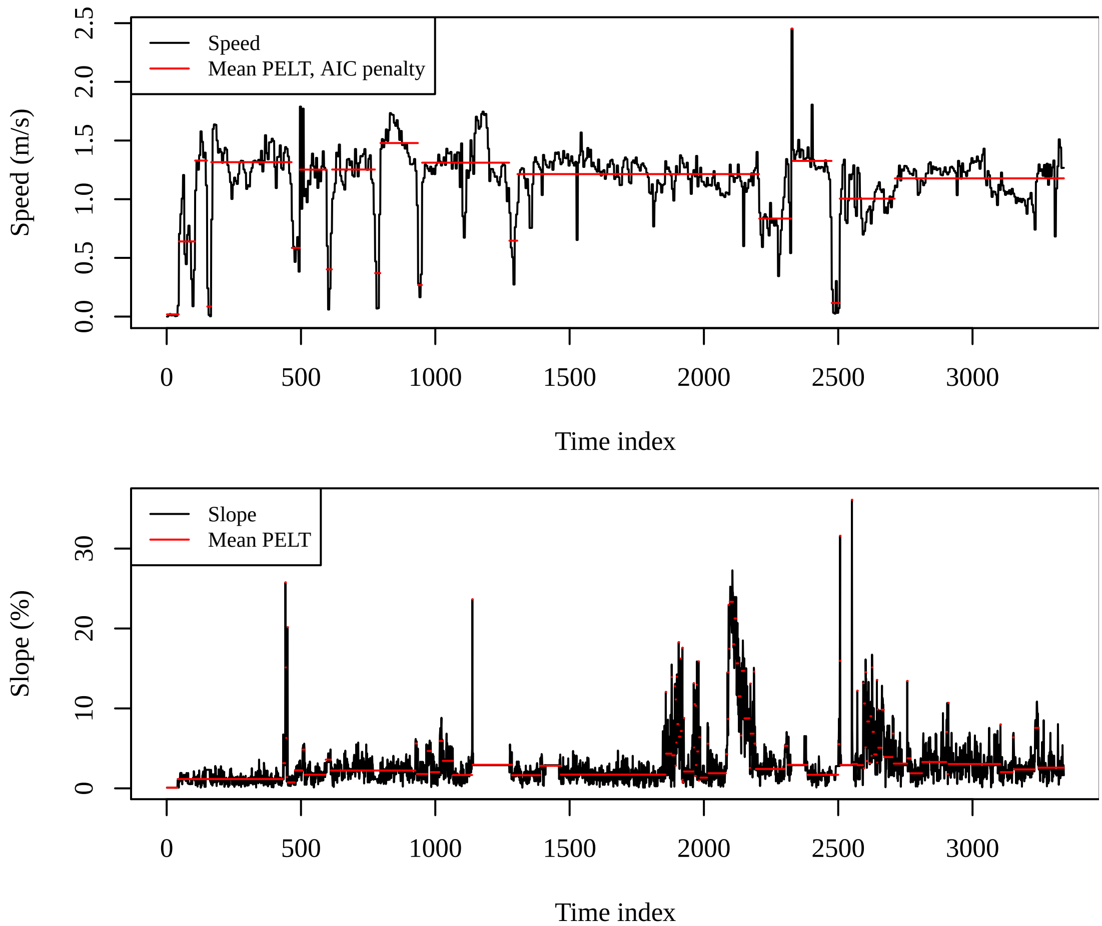


Figure 4.14.: Change point segments in speed and slope for the Leica route

4.4.4. Change point and Segments found for the bike route

For testing the accelerometer application, a route with GPS and the accelerometer app was conducted on the bike. This resulted into the following data. Figure 4.15 shows the route with the bike. The left zoom square shows a right crossroad, where the bike path is interrupted by another type of road. Going from concrete to tiled paving. See figure 4.16 showing a Google street-view of the bicycle lane changing to tiles at the crossing. The middle square shows a stop with the bike, before crossing the road. Here all indicators show a change point. The speed, slope, and acceleration in vertical direction. The right square shows a street with speed bumps that have to be crossed with the bike as well. The slope change points, indicate roughly these bumps, though they do not show in any other parameter.

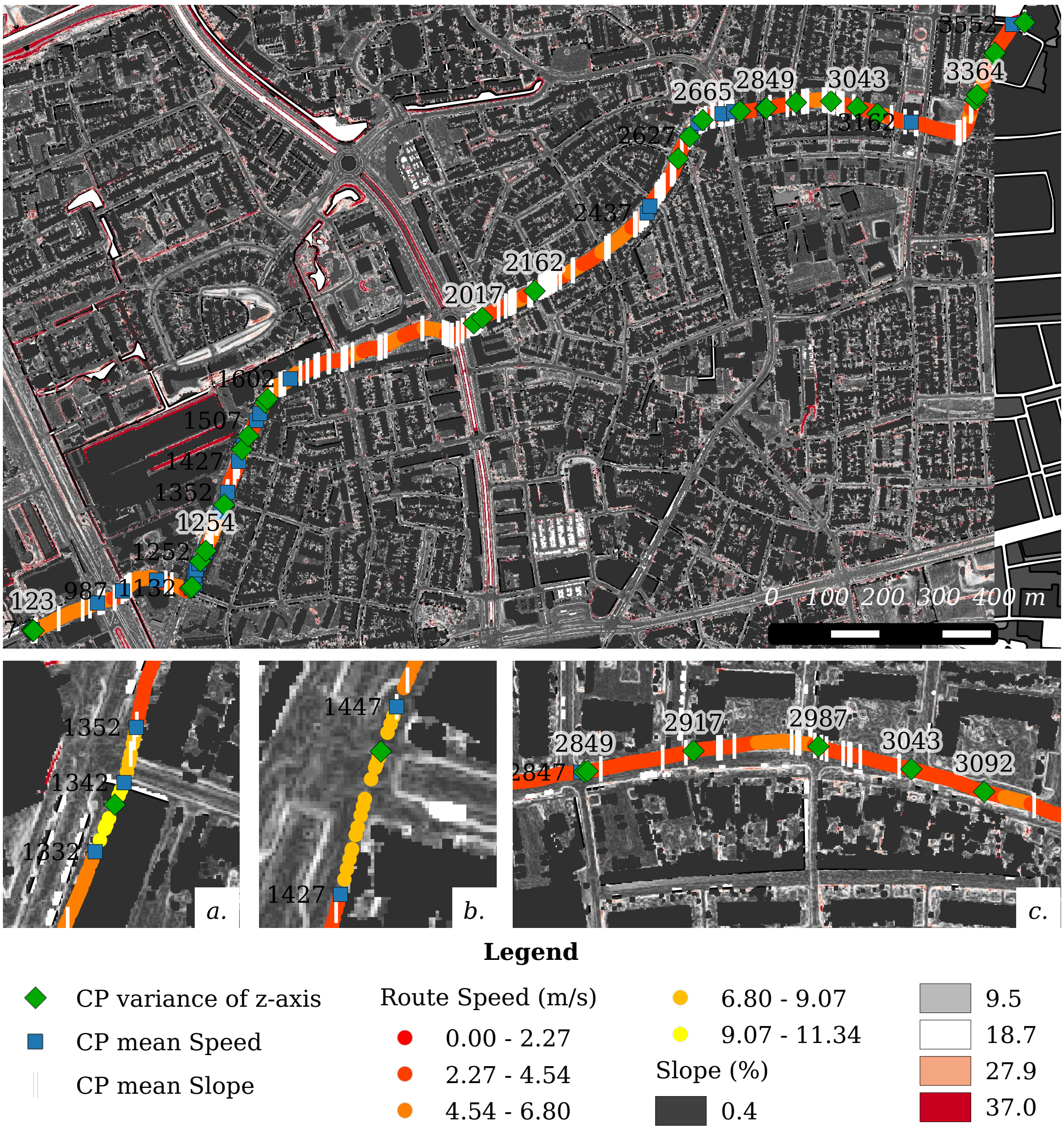


Figure 4.15.: Change points for the Bike route

Figure 4.16.: Google street-view of cross road, bicycle lane change.

Table 4.9.: Summary

..	Slope	Speed	Variance z-axis
Changepoint type	Change in mean	Change in mean	Change in variance
Method of analysis	PELT	PELT	PELT
Test Statistic	Normal	Normal	Normal
Type of penalty	MBIC with value, 24.5802	Manual with value, 12.2901	Manual with value, 12.2901
Minimum Segment Length	1	1	2
Maximum no. of cpts	Inf	Inf	Inf
Number of changepoints	195	27	32
Created Using changepoint version 2.2			

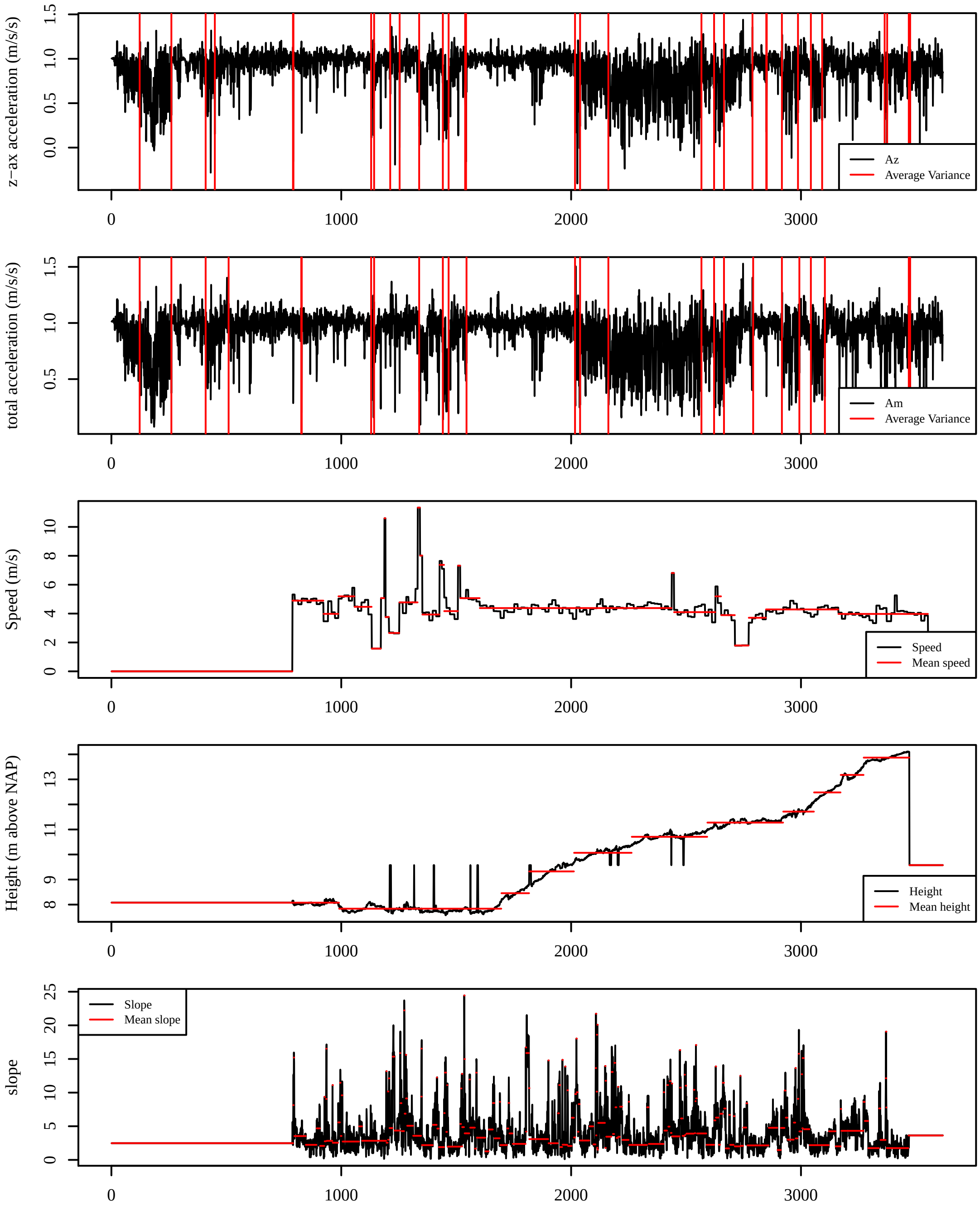


Figure 4.17.: Change point segments for the Bike route

5. Conclusion and discussion

The first section of this final chapter restates the research questions and presents the main conclusions of this research. Section 5.2 discusses the results outcomes and limitations of the research. Section 5.3 gives several recommendations to improve this research and for possible future research.

5.1. Conclusion

The objective of this research was to get the critical walkability factors that elderly experience while walking outdoors with a rollator, and explore the possibilities of geo-data and GIS analysis to visualize them, to raise more awareness and shed more light on the forgotten elderly pedestrian. This to trigger possible action at decentralized governments for increasing walking activity of elderly people. Consequently this may support health, the capability to live independently and grow old in their own house and environment. All may contribute to less need for healthcare and so reducing costs for elder care and improving the overall quality of life.

In order to analyse and map the critical walkability factors for elderly people depended on a rollator, in the urban outdoor space, the following sub-objectives and research questions were developed:

1. Find the critical factors for walkability in the urban outdoor environment for elderly depended on a rollator.

2. Map and analyse these critical factors,

    a) by analysing existing and available geo-data and testing its suitability and detail required

    b) by collecting geodata (measuring rollator movements with an accelerometer) and analysis

    c) by comparing these the two data sources (by using the change point method)

To find the critical walkability factors or urban outdoor environment for elderly people, with a rollator a literature study was conducted and interviews were held. This showed that there are many criteria mentionable to improve on for the elderly pedestrian. The top 3 of critical walkability factors were, wrongly parked bikes and cars, irregular cobbled surfaces and sloping pavements. The small part of interviews held with rollator users, underline the importance of the quality of the pedestrian area. The most important thing mentioned is, that, when surfaces will be more smooth, and surroundings less exhausting, longer and more comfortable walks will be able. Also confirmed is that the older peoples' perceived needs as pedestrian in the outdoor urban environment are considered important by the older people themselves. This research found walkability factors in line with previous researches and contributes to the knowledge specifically for Amsterdam. From the final list of critical factors assembled by all the findings, one of the main irritations specifically for Amsterdam are wrongly parked bikes and cars. Mainly due to the small pavement areas and parking on the pavements. Many road users, hardly think about the less impaired road users while parking their bike outside, against a lantern pole, and so blocking the pavements for wheelchair or rollator users. Next to this, research into the policy design and interviews with the municipality showed that policy design, does not take pedestrians into account sufficiently. Let alone, the elderly or mobile impaired pedestrian.

In order to map and analyse these critical factors, the first step was to analyse existing geo-data and test the detail required. Only the work Matthews et al. (2003), Modelling Access with GIS in Urban Systems [25], Svensson (2010) [37] and Duncan et al. (2011) with Walk Score: Estimating Neighbourhood Walkability [14] provide methods for quantifying walkability factors in a GIS system. They use a multi-criteria model with quantitative and qualitative techniques to make visible how the build environment can be hostile for the mobile impaired. For this research only a few datasets were used. The GBKA and the AHN2. An attempt was made to collect data on the location of curbs, ramps, what the material of the surface is etc. Though, there is no indication in the available data-sets of Amsterdam whatsoever on where curbs are located, how high they are, and whether there are ramps placed or where the curb is lowered. Besides this, no information could be found about the exact type of material of the surface or maintenance activities. Only an overview map showing material use per neighbourhood is available, see the Puccini map in annex A.3

The first step was to determine the pedestrian area with the available GBKA and have a look at is general characteristics and quality. A new approach had to be invented, as Matthews et al. did, for no label was attached with which target group the dedicated polygon belongs to. A small pilot study was held for the Jordaan in Amsterdam to see its suitability. The own approach to determine which areas are pedestrian area, showed rather high numbers for pedestrians. Around 53% of the public space in the test area Jordaan, belonged to pedestrians. A surprising amount as often in Amsterdam, pedestrians pavements are very narrow. This did however, include parking plots and public squares and the calculated area contains a lot of poles, bike racks, traffic signs or any other object placed on the pavement. The approach showed that an automatic approach is hard for classifying the polygons, and many mistakes are made in the data set.

Secondly, the AHN2 was used to derive sloping pavements above 4% slope. A lot of roads, classified for motorized transport showed average values below the 4% slope, while many pedestrian classified areas, had a slope higher then 4%. In numbers, the allowable 4% of slope for pedestrian pavement reduced the optimal pedestrian area to only 8%. Showing a lot of area being too steep for pedestrian allowable limits. While roads, for motorized transportation have less steep slopes, around 38% is below the 4% slope.

In conclusion, the GBKA showed that in the available geo-data of the municipality, still lacks detail and is insufficient for quick pedestrian analysis as the pedestrians are forgotten. This confirms the statements of the introduction, that pedestrians are forgotten in data. Only the AHN2 promises good usage for pavement analysis as it gives good insight in the sloping pavements and is detailed enough to detect curbs.

The collection of own data is done by measuring rollator movements whit an accelerometer. Works from Weiss et al. 2014 and Wang et al. 2015 gave the inspiration to work with the concept of a Smart Walker. Several test routes were walked during the rollator loop. These, unfortunately failed to measure the accelerometer sensor and were not usable. Other tests, walking the rollator myself and measuring different surfaces, showed that irregular surfaces can be measured with a accelerometer. The different kind of surfaces showed clear distinctions in the amount of vibrations when looking at the variance over the measured track. With grass and stones having the highest variance and vibrations and smooth concrete the lowest. When comparing this to a research done by Matthews et al. (2003) a correlation of 0.72 is found. Indicating the two studies do correlate but not highly. This, because the surfaces of Matthews and this research were probably not the exact same, what was measured differs and measurement methods differ. Matthews measured surface hindrance as the accelerometer measures the vibration effect on the rollator. Though, a correlation exist between vibration of the rollator and surface hindrance. And that surface hindrance can be approached with an accelerometer as well.

In order to compare both methods, using existing geo data to map walkability factors and comparing and testing them with a Smart Walker, a change point analysis was used. the change point method shows an interesting concept for detecting obstacles during a walking route. Several locations can be indicated where the walking behaviour (speed), the slope of the location, and the accelerometer behaviour fall together as expected, a large obstacle is detected. Also some peaks in the acceleration of the z-axis are located around imperfections in the pavement and are not accompanied by speed changes, indicating a small obstacle. Though, breaks and stops by the participant are also included. Several interesting events in the walking routes are that almost all change points for speed, in the Leica route, can be explained through logical reasoning. Also the change points in the z-axis acceleration in the walking route with the MeetRollator seem to be related to the true situation. This however, cannot be stated definitively as here the GPS performed poorly and so the points cannot be accurately compared to the location. Overall, the most change points in the z-axis acceleration occur where obstacles are taken, the route is started or ended. On the larger straight segments of the route, where the pavement stays nearly the same and walking speed is continuous, less change points can be found. The big amount of wrong points in the slope change points, actually originate from the inaccurate location determination and resulted in extracting values form the slope raster at the wrong location. Hopefully, we can add obstacle detection and surface quality monitoring as another possible application to the Smart Walker, next to fall protection, early warning systems, health monitoring, navigation help or cognitive assistance.

5.2. Discussion

5.2.1. The forgotten pedestrian

When policy design documents and the contacts from the municipality state that the pedestrian area is often the residual area in design and has the least priority, the arguments from the introduction are confirmed, that indeed, the pedestrian is forgotten in design. Moreover, this applies for the total group of pedestrians, not specifically for the mobility impaired pedestrians, who even require a more well designed public space.

Also the forgotten pedestrian in data is confirmed. Not only the PQN report states that there is not enough data on pedestrians [33], also Matthews et al. (2003) [25] encounters the first main problem, that no data is held on pavement centrelines. The basic layer for a GIS model is to know, what is pedestrian area or not. Our own research, confirmed that the GBKA, the most detailed topology dataset of the municipality of Amsterdam, did indeed, contain no label on whether it was a road for cars or a pavement for pedestrians. Through a own set up analysis of general assumptions a approximation to label the polygons was conducted. This, seemed more difficult then expected. Matthews stated that precise pedestrian routes can be mapped manually. [25]

5.2.2. Interviews with elderly

As Stahl et al. 2008 stated, user involvement leads to research of grater relevance to people and the findings more likely to be implemented. [36] Their research is all based on the problems identified by elderly people and therefore of great relevance. Also for this study the involvement of elderly with a rollator was perceived as important. For the conducting researcher to be young and not having any experiences with mobility problems, it was key to hear from first hand. The first intention was to interview at least 20 elderly in Amsterdam, that walk outside regularly with a rollator. Unfortunately, this seemed harder then firstly assumed. Elderly care houses were not keen on cooperating. Calling would often result into a redirection to the location manager and no answer to the e-mails. Some institutions did show some enthusiasm. The Flessenoord and .. were willing to cooperate, but could only provide 3 participants who walked outside with the rollator. One participant was not available in the end. The Buurtzorg Centrum were also enthusiastic. After several calls and e-mails, they never responded with possible contacts for participants. In the end the short interviews at the Rollatorloop gave a bit more insight. Though, these interviews were conducted rather quickly without any control system.

The participants that did answer already showed how strong the influence of the personal preferences has on the perception to its surroundings. One of the participant really likes walking while the other rather stays inside. This strongly influenced their feelings and emotions they had to walking outside. Through this we can say there is a lot of differences in rollator users. Perception of safety is different for every individual. Very personal determinants.

When going to the Rollatorloop, noticed was that there are a lot of different rollators. This research did not take into account the different type of rollators available. Thought, the type of wheels and structure of frame might really influence the measurements and can result in different data characteristics.

5.2.3. The Accelerometer sensor

The application, Physics Toolbox Accelerometer, was a good application and easy to use for measure the accelerometer sensor of the phone. However, the first versions of the application made the app stop measuring when the phone went in sleeping mode. The test rides done on the bike could have been done better. Also the exploration of the test data was too quick and roughly done for the researcher was not familiar with these kind of datasets. A better planning of experiments was needed, and a more clear focus in the first stage of the experiments was lacking. The overall time planning was weak. After a more in depth research into the application behaviour and settings and contacting the developer, more controlled knowledge was gathered about the working of the application. Now, after the application version change and the improvement of the application, it is perfect for using it in this kind of research. If more time was available, again elderly could have been contacted to do the same kind of measurements again. With the Leica and a good working accelerometer application.

The accuracy or errors from the accelerometer are unknown, as the quality of the sensor in the phone is unknown and not researched. Also the exact meaning of the application values are unknown. These could not be tested, as no good reference accelerometer sensor was available.

Overall the outcome of the measurements seemed quite credible. Also the tests with putting the accelerometer flat on the table, did not show any weird peaks or deviations.

5.2.4. Influenced experiments

After the failed measurements, the researcher herself conducted some extra walks. This could give a wrong image on the measured walking behaviour outcome. From Wang et al. we learned that there is no difference in walking gait characteristics between elderly and young people. [44] But that elderly are more used to handling a rollator compared to young people, for which a rollator could be an obstacle in moving more easily. Walking with the rollator myself could have influenced the outcomes.

5.2.5. Spatial accuracy, detail is key

The GPS on the phone not exact enough. This resulted in wrong extraction of data values from the AHN2 and the slope raster. So these change points did not represent the true values for the location.

No hard conclusions can be drawn for the accuracy is not known.

5.2.6. changepoitn method

Now, the urban environment will never be optimal, so certain change points will indicate not so important happenings.

starten met lopen, is een harde duw tegen de rollator? waardoor er een piek in de accelerometer data ontstaat.

Could not use trend, seasonality and random analysis, for no seasonality in the data. Surface hindrance changes per surface. Obstacles show more as abnormalities. BFASTt method. BFAST, Breaks For Additive Season and Trend, integrates the decomposition of time series into trend, season, and remainder components with methods for detecting and characterizing change within time series. BFAST BFASTmonitor: http://bfast.r-forge.r-project.org/

5.3. Reccomendations

Recommendations to improve this study

- Conduct more interviews with elderly living in Amsterdam and walking with a rollator outdoors, to get a better understanding of the location specific problems. Thoug, trough the literature research and the few interviews held, already a good insight is presented.

- In order to conduct a goo pedestrian area classification, it would have been better not to include parking plots into the pedestrian area. Comparing the classification methods with manual classification could have said more about the accuracy of the method. But was too time consuming for this research.

- Conduct more controlled experiments with elderly themselves. Also comparing routes walked in a controlled environment against routes walked in the real living environment. This can give better insights if this methods works for detecting obstacles along the real walking routes of elderly, when walked by themselves. Instead of a young vital person walking with a rollator.

- Use better GPS systems, like the Leica stystem for location determination. The detail for which the detection of obstacles is needed, has to be very precise. The slightest deviation can give falsehoods in the change point detection for slope. The research of Wang et al. [44] uses exact accelerometer to monitor the displacement for every step made. By using this method the route of a person could be exactly determined from the starting point, with an accuracy of about 1 cm and no GPS would be needed. This would also require a standard measure rollator were the exact distances of the sensor to the wheels and frame has to be known.

- The AHN2 promised good possibilities to detect surface quality and sloping pavements. Even the detection of curbs and ramps could be possible. More research to the application and possibilities of the AHN2 can be interesting.

Recommendations for future research:

- Find a possible way to quantify the relation between surface hindrance and the effort needed for elderly with a rollator to walk on. For example measuring energy use of elderly. Also the perception of elderly to different surface circumstances could be measured. An interesting link could be the report from Hogertz et al. 2010 [33], which tries to measure skin conductivity as a quantitative measure for arousal.

  Possible applications of smart phone with accelerometer use, for measuring rollator movements or surface resistance. Translate this to the amount of energy that elderly consume.

- Possible applications might be to detect the kind of surface material from the accelerometer signatures. Create a specific signature for a specific surface material. What has to be taken into account is the different set of rollators that exists. Which react differently to surface irregularities.

- This study could be used to create a low cost, non-intrusive method for identifying the location of obstacles on the route of elderly with a rollator. A more in detail method could be designed, that automatically filters out priority obstacles where the data changes in a specific way.

- using the change point method and regarding a route as a time series dataset could be an interesting method to detect walking behaviour, driving behaviour changes.

- Detecting wrongly parked bikes and cars. or raise more awareness under citizens about the problems they cause when parking their bikes wrong. I noticed I never thought about the placement of my bike in relation to the rest of the pavement until I started this project. It makes you look with different eyes and makes you more aware of were to park your bike so enough space is left for others to pass through.

5.4. Final words

It is proven that for elderly, who are more vulnerable, environmental attributes can be barriers to an active engagement in urban life. The quality of the immediate environment is a significant determinant of elders well-being, independence and quality of life. Developing ways to quantify their problems and add more data on their walkability quality could lead to more insight and hopefully to interventions on pavement level. In the near future, there will be more elderly who are willing to live independently and grow old in their own home. In order to facilitate this, we have to look forward and adapt the environment now when we are still young.

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A. Appendix

A.1. Table of contents DVD

The DVD that accompanies this thesis report contains the following information:

Documents

- Final thesis report (Latex structure and PDF)
- Bibliography, bibtex

Presentations

- Midterm presentation (PDF)
- Final presentation (PDF)

Literature and interview

- Total list of literature findings
- Questionnaire elderly (PDF)

Data

- All measured routes
- All shapefiles
- QGIS files for all maps used in report

Applications and scripts

- R-script for ..

A.2. Walkability criteria total overview

Level	Criteria / indicators	Sub-themes	Found in literature	Perceived importance from literature source
Crossings	**Accessibility**			
	Crossings with traffic light		Bernhoft and Carstensen 2008	High
	Crossings with traffic light		Verschuur 2014	
	Crossings with traffic light		Dunbar et al. 2004	
	Crossings with zebra crossing		R.T., 1991	
	Crossings with zebra crossing		Wennberg et al. 2010	
	Crossings with zebra crossing		Borst et al. 2008	Positively related
	Zebra crossings		Bernhoft and Carstensen 2008	Dangerous
	No crossing		Verschuur 2014	
	lack of crosswalks		Rosenberg et al. 2012	
	Quality			
	Misplaced crossing		Rosenberg et al. 2012	
	Crossings no curb at zebra crossings		Wennberg et al. 2010	
	Traffic lights without audio signal		Verschuur 2014	
	clearly marked crosswalks		Rosenberg et al. 2012	
	Obstruction			
	Route Attractiveness			
	Safety			
	Too short crossing time		Rosenberg et al. 2012	
	Too short crossing time		Vine et al. 2012	major concern
	Too short crossing time		Dunbar et al. 2004	
	Bad overview crossing		Rosenberg et al. 2012	
	Bad overview crossing		Vine et al. 2012	
	limited sight near a crossing		Verschuur 2014	negative
	Fast speed traffic at crossing		Rosenberg et al. 2012	
	More traffic islands		Dunbar et al. 2004	

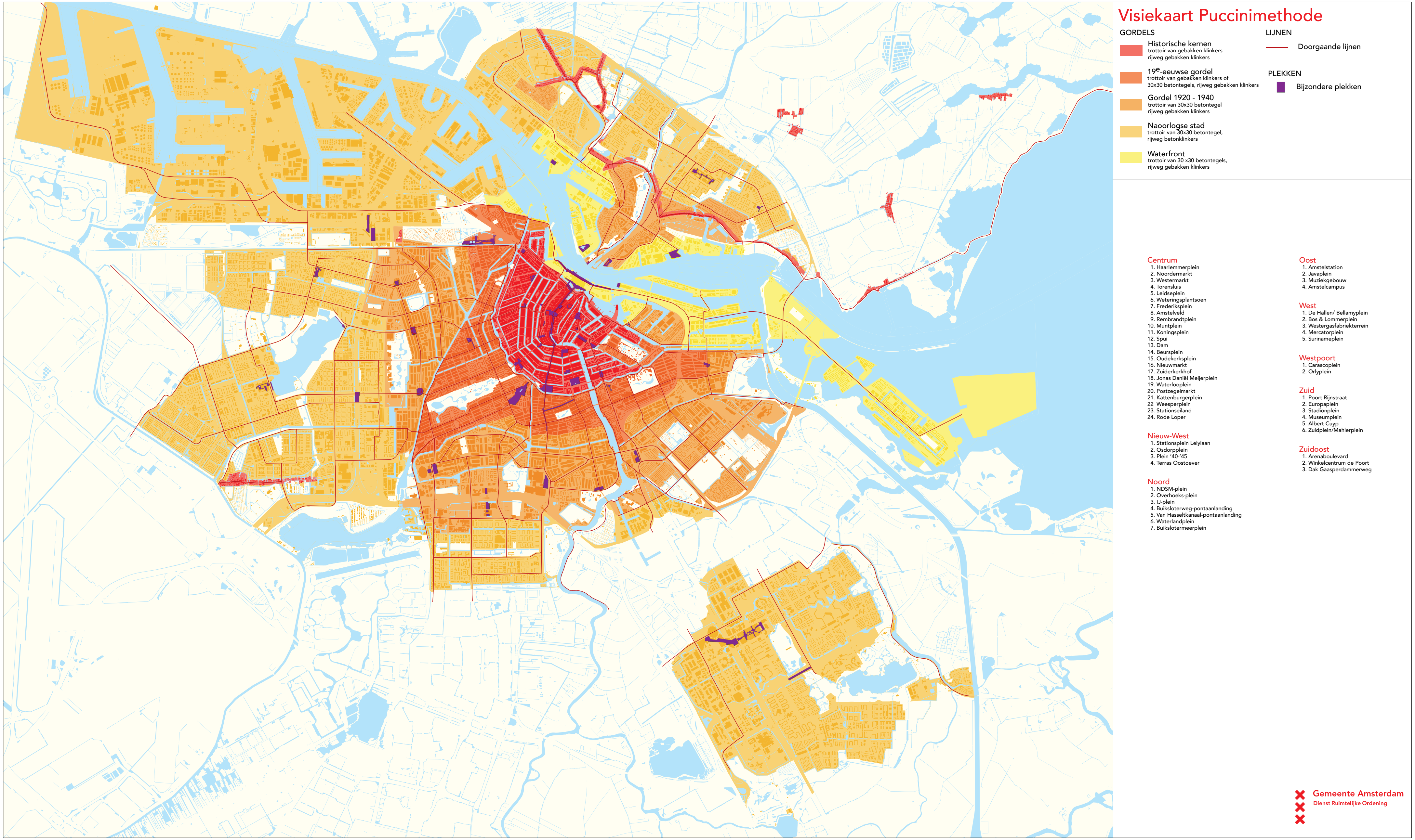
Level	Criteria / indicators	Sub-themes	Found in literature	Perceived importance from literature source
Pavement	**Accessibility**			
	Presence of pavement		Bernhoft and Carstensen 2008	High
	Presence of pavement		Borst et al. 2008	
	Presence of pavement		Rosenberg et al. 2012	Key theme
	No pavement		Verschuur 2014	
	Width of the pavement		Rosenberg et al. 2012	
	narrow pavements		Matthews et al. 2002	Most cited urban barriers
	narrow pavements		Vine et al. 2012	
	Curbs	precense	Borst et al. 2008	
	Heigh curbs		Matthews et al. 2002	Most cited urban barriers
	Heigh curbs		Hovbrandt et al. 2007	
	Heigh curbs		Werkgroep Wageningen Toegankelijk 2012	
	Heigh curbs		Verschuur 2014	
	low curb		Wennberg et al. 2010	
	Curb ramps	Lack of	Rosenberg et al. 2012	Key theme
	Location pavement ramps		Borst et al. 2008	
	Stairs		Borst et al. 2008	Positively related
	Stairs		Verschuur 2014	
	Precence of stairs		Rosenberg et al. 2012	
	steps		Matthews et al. 2002	Most cited urban barriers
	No alternative to stairs		Rosenberg et al. 2012	
	Quality			
	Smooth surface		Bernhoft and Carstensen 2008	High
	Smooth surface		Rosenberg et al. 2012	Key theme
	Smooth surface		Wennberg et al. 2010	
	uneven pavement		Hovbrandt et al. 2007	
	uneven pavement		Verschuur 2014	
	Cobbled surfaces		Matthews et al. 2002	Most cited urban barriers
	Slippery surfaces	grass, unlevel ground	Rosenberg et al. 2012	
	Material pavement	Asphalt, stones, gravel	Matthews et al. 2002	Most cited urban barriers
	Material pavement		Werkgroep Wageningen Toegankelijk 2012	
	Maintenance of pavement	debris, cracks, holes	Matthews et al. 2002	Most cited urban barriers
	Lack of adeuate maintenance		Verschuur 2014	
	homogenity material	holes, loose tiles, cracks	Wennberg et al. 2010	
	homogenity material	roots	Rosenberg et al. 2012	
	Wrong location of curbs		Rosenberg et al. 2012	
	too steep curb ramps		Rosenberg et al. 2012	Key theme
	Dropped curbs	lack of	Matthews et al. 2002	Most cited urban barriers
	dangerous curb ramp conditions		Rosenberg et al. 2012	
	Slope of pavements		Borst et al. 2008	
	Slope of pavements		Werkgroep Wageningen Toegankelijk 2012	
	Lack of handrail of stairs		Wennberg et al. 2010	
	Lack of handrail of stairs		Rosenberg et al. 2012	
	well-contrasted steps of stairs		Wennberg et al. 2010	
	well-contrasted steps of stairs		Verschuur 2014	
	Handrails on stairs		Verschuur 2014	
	Objects Barriers			
	Objects on the pavement		Borst et al. 2008	
	Objects on the pavement		Rosenberg et al. 2012	
	Poles		Rosenberg et al. 2012	
	Parked bikes		Rosenberg et al. 2012	
	Parked bikes		Hovbrandt et al. 2007	
	Parked bikes		Wennberg et al. 2010	
	parked bikes/scooters		Verschuur 2014	negative
	Wrongly parked bikes		Werkgroep Wageningen Toegankelijk 2012	
	Trees			
	drain cover			
	Parked cars blocking side-walk		Rosenberg et al. 2012	
	Parked cars blocking side-walk		Werkgroep Wageningen Toegankelijk 2012	
	ramps or sidewalks blocked by parked cars		Verschuur 2014	
	obstructions blocking ramps		Rosenberg et al. 2012	
	Advertisement boards		Werkgroep Wageningen Toegankelijk 2012	
	Blocking commercial signs		Wennberg et al. 2010	
	Gutters		Matthews et al. 2002	Most cited urban barriers
	Gutters		Wennberg et al. 2010	
	Rain Gullies in pavement		Verschuur 2014	
	protruding portals, facades, basement windows		Verschuur 2014	
	green maintenance	branches cut	Wennberg et al. 2010	
	Branches hanging over pathway		Verschuur 2014	
	Route Attractiveness			
	Dog droppings		Borst et al. 2008	Very negative
	dog poo		Verschuur 2014	negative
	Garbage	bags, litter	Borst et al. 2008	
	Litter		Verschuur 2014	
	Garbage		Wennberg et al. 2010	
	Aesthetics, precence of unattractive features	litter, graffiti, garbage, smoking	Rosenberg et al. 2012	
	Aesthetics, precence of attractive features	nature, green, water, animals, art	Rosenberg et al. 2012	
	Safety			

Level	Criteria / indicators	Sub-themes	Found in literature	Perceived importance from literature source
Street	**Accessibility**			
	availabilty bridge			
	continious guidance routes		Wennberg et al. 2010	
	clear warning markings		Wennberg et al. 2010	
	clear contrast markings		Wennberg et al. 2010	
	Quality			
	Slope of the street		Rosenberg et al. 2012	Key theme
	too steep		Matthews et al. 2002	Most cited urban barriers
	Slope		Wennberg et al. 2010	
	hilly topography		Vine et al. 2012	
	hills		Verschuur 2014	
	Hills		Rosenberg et al. 2012	
	Slope of bridges			
	Obstruction			
	Route attractiveness			
	Available public toilets		Verschuur 2014	
	Availability shelter againts rain		Rosenberg et al. 2012	
			Dunbar et al. 2004	
	Protection from sun and rain		Verschuur 2014	
	Availability resting benches		Borst et al. 2008	
	Availability resting benches		Rosenberg et al. 2012	
	Availability resting benches		Hovbrandt et al. 2007	
	Availability resting benches		Dunbar et al. 2004	
	Availability resting benches		Wennberg et al. 2010	
	benches		Verschuur 2014	positve
	Trees along the route		Borst et al. 2008	Positively related
	Trees along the route		Verschuur 2014	
	Front gardens		Borst et al. 2008	Positively related
	Front gardens		Verschuur 2014	
	Parks		Verschuur 2014	
	Water features		Verschuur 2014	
	Nature animals flowers		Verschuur 2014	
	Safety			
	Overall business on the street	Pedestrians		
	Overall business on the street	bycles		
	Overall business on the street	traffic		
	Vehicle-pedestrian interaction		Vine et al. 2012	Troublesome
	Vehicle pedestiran seperation		Wennberg et al. 2010	
	Vehicle pedestiran seperation	Green strips	Borst et al. 2008	
	Vehicle pedestiran seperation		Dunbar et al. 2004	
	speed control measuerments			
	Speedlimit		Dunbar et al. 2004	
	low traffic roads		Rosenberg et al. 2012	
	mixed traffic places		Verschuur 2014	negative
	cyclists in pedestrian area		Wennberg et al. 2010	negative
	scooters driving on sidewalks		Verschuur 2014	negative
	two direction traffic.		Verschuur 2014	negative
	Precense of street lights		Bernhoft and Carstensen 2008	Low
	Precense of street lights		Rosenberg et al. 2012	Key theme
	Precense of street lights		Hovbrandt et al. 2007	
	Precense of street lights		Wennberg et al. 2010	
	poor lightting		Verschuur 2014	negative
	Precense of activity of other people		Verschuur 2014	
	Blind walls		Verschuur 2014	
	no traffic islands		Verschuur 2014	negative
	narrow scary		Verschuur 2014	

Level	Criteria / indicators	Sub-themes	Found in literature	Perceived importance from literature source
Environment	**Accessibility**			
	Pedestrian network	nodes in network	Vine, 2012	
		Short routes	Bernhoft and Carstensen 2008	Low
		quick routes	Bernhoft and Carstensen 2008	Low
	Public transport nodes		Verschuur 2014	positive
	Public transport nodes		Borst et al. 2008	Positively related
	no disabled parking		Verschuur 2014	negative
	Lack of handicapped parking spaces		Rosenberg et al. 2012	
	Parking is far form desitination		Rosenberg et al. 2012	
	Quality			
	obstuction			
	Route attractiveness			
	Air pollution			
	Land use mix		Vine et al. 2012	
	Green			
	Landmarks and monuments			
	Precense of highways			
	Architectual varaity			
	Precense of facilities			
		Schools		
		Youth centres		
		Club and pubs		
		Shops	Borst et al. 2008	Positively related
		shops	Verschuur 2014	positive
		Night activities		
		Catering	Borst et al. 2008	
		Catering	Verschuur 2014	positive
		Buisness buildings	Borst et al. 2008	
	Empty buildings		Borst et al. 2008	weak negative
	Building density		Borst et al. 2008	Negatively related
	Density of dwellings		Verschuur 2014	
	Parks		Borst et al. 2008	Positively related
	City centre		Borst et al. 2008	Positively related
	Traffic volume		Borst et al. 2008	Positively related
	traffic volume		Verschuur 2014	
	High rise buildings		Borst et al. 2008	Negatively related
	Waste terrrain		Borst et al. 2008	
	Graffiti		Borst et al. 2008	Very negative
	Graffiti		Wennberg et al. 2010	
	industry		Verschuur 2014	negative
	vacant buildings		Verschuur 2014	negative
	playgrounds		Verschuur 2014	positive
	loitering youth		Verschuur 2014	negative
	Safety			
	Traffic density		Bernhoft and Carstensen 2008	Low
	Traffic density		Hovbrandt et al. 2007	
	traffic volume		Verschuur 2014	negative
	Criminality		Rosenberg et al. 2012	

Level	Criteria / indicators	Sub-themes	Found in literature	Perceived importance from literature source
Weather	Slippery	Weather	Rosenberg et al. 2012	Key theme
	rain		Rosenberg et al. 2012	Key theme
	wind		Rosenberg et al. 2012	Key theme
	Heat	Weather	Rosenberg et al. 2012	Key theme
	sun		Rosenberg et al. 2012	Key theme
	sunshine		Verschuur 2014	positive
	stench		Verschuur 2014	negative
	cold/windy		Verschuur 2014	negative
	fresh air		Verschuur 2014	positive
	quit		Verschuur 2014	positive
	snow removal		Wennberg 2009	

A.3. Puccini Map Amsterdam


Visiekaart Puccinimethode
GORDELS
Historische kernen
trottoir van gebakken klinkers
rijweg gebakken klinkers
19e-eeuwse gordel
trottoir van gebakken klinkers of
30x30 betontegels, rijweg gebakken klinkers
Gordel 1920 - 1940
trottoir van 30x30 betontegel
rijweg gebakken klinkers
Naoorlogse stad
trottoir van 30x30 betontegel,
rijweg betonklinkers
Waterfront
trottoir van 30 x30 betontegels,
rijweg gebakken klinkers
LIJNEN
Doorgaande lijnen
PLEKKEN
Bijzondere plekken
Centrum
1. Haarlemmerplein
2. Noordermarkt
3. Westermarkt
4. Torensluis
5. Leidseplein
6. Weteringsplantsoen
7. Frederiksplein
8. Amstelveld
9. Rembrandtplein
10. Muntplein
11. Koningsplein
12. Spui
13. Dam
14. Beursplein
15. Oudekerksplein
16. Nieuwmarkt
17. Zuiderkerkhof
18. Jonas Daniël Meijerplein
19. Waterlooplein
20. Postzegelmarkt
21. Kattenburgerplein
22 Weesperplein
23. Stationseiland
24. Rode Loper
Nieuw-West
1. Stationsplein Lelylaan
2. Osdorpplein
3. Plein '40-'45
4. Terras Oostoever
Noord
1. NDSM-plein
2. Overhoeks-plein
3. IJ-plein
4. Buiksloterweg-pontaanlanding
5. Van Hasseltkanaal-pontaanlanding
6. Waterlandplein
7. Buikslotermeerplein
Oost
1. Amstelstation
2. Javaplein
3. Muziekgebouw
4. Amstelcampus
West
1. De Hallen/ Bellamyplein
2. Bos & Lommerplein
3. Westergasfabriekterrein
4. Mercatorplein
5. Surinameplein
Westpoort
1. Carascoplein
2. Orlyplein
Zuid
1. Poort Rijnstraat
2. Europaplein
3. Stadionplein
4. Museumplein
5. Albert Cuyp
6. Zuidplein/Mahlerplein
Zuidoost
1. Arenaboulevard
2. Winkelcentrum de Poort
3. Dak Gaasperdammerweg
Gemeente Amsterdam
Dienst Ruimtelijke Ordening

A.4. Questionnaire

NR

Datum:

Begeleid door:

Vragenformulier

Onderzoek naar de beloopbaarheid van de buitenshuise gebruiksomgeving voor ouderen met een rollator

Aanwijzingen bij deze vragenlijst

- Het invullen van de vragenlijst kost u ongeveer een half uur.
- Lees elke vraag eerst helemaal door voordat u een antwoord kiest.
- Kruis dan het antwoord aan dat het beste bij u past.
- Kruis bij elke vraag maar één antwoord aan. Als u meer dan één antwoord aan mag kruisen, dan wordt dat bij de vraag genoemd.

- Als u het moeilijk vindt om de vragen te begrijpen of in te vullen, vraag dan hulp aan een van de onderzoeks begeleiders.

- Bent u klaar, kijk dan of u geen vragen vergeten bent.

Vul hieronder uw persoonlijke gegevens in.

Naam:

Geboorte datum:

Geslacht:

- ☐ Man
- ☐ Vrouw

Adres en huisnummer

Postcode

Plaats

1. Hoeveel jaar woont u al op dit adres?
   - ☐ 0 tot 1 jaar
   - ☐ 2 tot 5 jaar
   - ☐ 5 tot 10 jaar
   - ☐ 10 tot 20 jaar
   - ☐ langer dan 20 jaar

Gebruik van de Rollator & Gezondheid.

1. Heeft u een Rollator nodig tijdens het lopen buitenshuis?
   - ☐ Altijd
   - ☐ Vaak
   - ☐ Soms
   - ☐ Nooit

2. Beschrijf kort de lichamelijke problemen die u ervaart tijdens het lopen zonder Rollator.

3. Beschrijf kort de lichamelijke problemen die u ervaart tijdens het lopen met Rollator.

4. Hoe is uw gezondheid in het algemeen?
   - ☐ Uitstekend
   - ☐ Goed
   - ☐ Redelijk
   - ☐ Slecht
   - ☐ Zeer slecht

Loopgedrag met de Rollator.

Deze vragen gaan over wekelijkse wandelingen die u maakt met uw rollator. De supermarkt, huisarts, apotheek, vrienden, familie enz. Dus normale wandelingen die u maakt in uw dagelijks leven.
NIET: Bijzondere uitstapjes en evenementen

1. Hoe vaak gaat u gemiddeld met uw rollator naar buiten in één week?
   ______________________keer per week.

2. Wat is de verste afstand die u loopt met uw rollator in de week?
   ______________________meter.

3. Hoe lang duurt uw verste wandeling met uw rollator?
   ______________________minuten.

4. Bent u in staat nog verder te lopen met uw rollator?
   - ☐ Ja, ik kan ______________meter afleggen.
   - ☐ Nee

5. Bent u wel eens gevallen buitenshuis tijdens het lopen met of zonder uw rollator?
   - ☐ Ja, al _________________ keer
   - ☐ Nee **sla vraag 6 en 7 over**

6. Waardoor ontstond(en) uw val(len)? *Meerdere antwoorden mogelijk*
En hoe vaak kwam dit voor?
   - ☐ Persoonlijke fout of medische reden .... _________keer
   - ☐ Een obstakel op de weg .... _________keer
   - ☐ Een omstander , die mij heeft omgestoten/afgeleid/aanviel _________keer
   - ☐ De drukte om mij heen werd te veel .... _________keer
   - ☐ Slechte verlichting .... _________keer
   - ☐ Geen idee .... _________keer
   - ☐ Anders, namelijk ______________________ .... _________keer

7. Gaat u minder vaak te voet naar buiten dan u zou willen, omdat u ooit gevallen bent tijdens het wandelen?
   - ☐ Ja
   - ☐ Nee

De buitenshuise gebruiksomgeving.

Geef aan per activiteit hoe vaak u hier per week naar toe gaat te voet met uw rollator.

Activiteit	
Werk	________keer per week
Supermarkt	________keer per week
Huisarts	________keer per week
Apotheek	________keer per week
Fysiotherapie	________keer per week
Sport & beweging, zwembad, sportschool	________keer per week
Winkelen, winkelcentrum	________keer per week
Recreatie wandeling: park, bos, strand	________keer per week
Familie bezoek	________keer per week
Vrienden bezoek	________keer per week
Buurt activiteiten (buurthuis)	________keer per week
Ouderen activiteiten (sociëteit, woongroep)	________keer per week
Café, restaurant, dansgelegenheid, hotel	________keer per week
Naar een openbaarvervoers punt zoals de bus of tram	________keer per week
Anders namelijk.....	________keer per week
	________keer per week
	________keer per week
	________keer per week
	________keer per week

Locaties op de kaart

Vraag voor dit onderdeel een van de onderzoeks begeleiders om u te helpen!

- Geef op de kaart de locaties aan met het juiste symbool.
- Teken op de kaart de route die u normaal loopt.
- Denk hierbij aan welke kant van de weg u loopt. Welke oversteek plaatsen u gebruikt.
- Waar u ergens op de weg loopt i.p.v. het voetpad.
- Maak de route zo gedetailleerd mogelijk!

Heeft niemand tijd? Dan kunt u vast doorgaan met het beantwoorden van de rest van de vragen.

Problemen tijdens het lopen met een rollator buitenshuis.

Kruis aan in welke mate de volgende situaties u hinderen tijdens het lopen met uw rollator buitenshuis. Komt u de situatie nooit tegen kruis dan 'Nooit'aan.

Kwaliteit van het voetpad	**Nooit**	**Zelden**	**Soms**	**Vaak**	**Altijd**
Slecht onderhouden voetpaden	1	2	3	4	5
Smalle voetpaden	1	2	3	4	5
Weinig voetpad opstapjes	1	2	3	4	5
Steile opstapjes	1	2	3	4	5
Hellende voetpaden	1	2	3	4	5
Te steile hellingingen (bruggen, heuvels)	1	2	3	4	5
Te steile afdalingen (bruggen, heuvels)	1	2	3	4	5
Oversteek plaatsen op onhandige locatie	1	2	3	4	5
Onoverzichtelijke oversteek plaatsen	1	2	3	4	5
Te weinig tijd met oversteken	1	2	3	4	5
Gemixte ruimte: fiets- en looppaden in één	1	2	3	4	5
Fietsers op het voetpad	1	2	3	4	5

Objecten	**Nooit**	**Zelden**	**Soms**	**Vaak**	**Altijd**
Fout geparkeerde auto's	1	2	3	4	5
Fout geparkeerde fietsen en scooters	1	2	3	4	5
Putdeksels	1	2	3	4	5
Paaltjes op de weg	1	2	3	4	5
Hondenpoep	1	2	3	4	5
Te weinig bankjes op te rusten	1	2	3	4	5
Te weinig openbare toiletten	1	2	3	4	5
Te weinig beschutting voor regen	1	2	3	4	5
Uitstekende portalen, gevels, kelderramen	1	2	3	4	5

Algemene drukte	**Nooit**	**Zelden**	**Soms**	**Vaak**	**Altijd**
Veel voetgangers	1	2	3	4	5
Veel geluid, harde geluiden	1	2	3	4	5
Veel verkeer	1	2	3	4	5

Veiligheid					
Enge steegjes	1	2	3	4	5
Slechte verlichting in de avond/nacht	1	2	3	4	5
Hangjeugd	1	2	3	4	5
Onveilig gevoel	1	2	3	4	5

Omgeving	**Nooit**	**Zelden**	**Soms**	**Vaak**	**Altijd**
Weinig groen	1	2	3	4	5
Slecht onderhouden omgeving	1	2	3	4	5
Lelijke gebouwen	1	2	3	4	5
Zwerf afval	1	2	3	4	5
Vuilniszakken	1	2	3	4	5
Stank	1	2	3	4	5
Wind	1	2	3	4	5

Zijn er nog obstakels en problemen waar u last van heeft en die niet in de lijst stonden? Schrijf ze dan hier op en geef aan hoe vaak u er last van heeft.

	Nooit	**Zelden**	**Soms**	**Vaak**	**Altijd**
	1	2	3	4	5
	1	2	3	4	5
	1	2	3	4	5
	1	2	3	4	5
	1	2	3	4	5
	1	2	3	4	5
	1	2	3	4	5
	1	2	3	4	5
	1	2	3	4	5
	1	2	3	4	5
	1	2	3	4	5
	1	2	3	4	5

Invloed van de omgeving op uw loopgedrag met uw rollator.

Kruis aan in hoeverre de volgende uitspraken overeen komen met uw ervaring.

	On-eens		Neutraal		Mee-eens
Mijn lichamelijke beperkingen zorgen ervoor dat ik minder vaak te voet naar buiten ga dan ik zou willen.	☐	☐	☐	☐	☐
De slechte beloopbaarheid van de omgeving zorgt ervoor dat ik minder vaak te voet naar buiten ga dan ik zou willen.	☐	☐	☐	☐	☐
De tastbare obstakels in de omgeving zorgen ervoor dat ik minder vaak te voet naar buiten ga dan ik zou willen.	☐	☐	☐	☐	☐
Ik loop gewoon om de tastbare obstakels heen, maar het zou makkelijker zijn als ze er niet waren.	☐	☐	☐	☐	☐
Ik voel me wel eens onveilig en onprettig in mijn omgeving (de ontastbare obstakels).	☐	☐	☐	☐	☐
Het onveilige gevoel dat de omgeving mij geeft, zorgt ervoor dat ik minder vaak te voet naar buiten ga dan ik zou willen.	☐	☐	☐	☐	☐
Ik ben bang dat ik buitenshuis val omdat de tastbare obstakels in mijn omgeving mij het lopen moeilijk maakt.	☐	☐	☐	☐	☐

	On-eens		Neutraal		Mee-eens
Ik ben bang dat ik buitenshuis val omdat de ontastbare obstakels in mijn omgeving mij het lopen moeilijk maakt.	☐	☐	☐	☐	☐
Omdat ik bang ben om te vallen ga ik minder vaak te voet naar buiten dan ik zou willen.	☐	☐	☐	☐	☐
Door het drukke verkeer in mijn omgeving ga ik minder vaak te voet naar buiten dan ik zou willen.	☐	☐	☐	☐	☐

Hieronder kunt u eventuele opmerkingen naar aanleiding van deze vragenlijst vermelden.

Vervolg onderzoek.

Er komt een vervolg onderzoek. Deze houdt in dat u 1 dag beschikbaar bent voor het volgende:

- Een diepte interview
- Één of meerdere wandelingen met een rollator met meetapparatuur en de onderzoeker op een gebruikelijke route van uzelf.

Heeft u interesse om mee te doen aan het vervolg onderzoek?

☐ **Ja** ***Vul de volgende vragen in***

☐ **Nee** ***De volgende vragen hoeft u niet meer in te vullen***

Bent u in staat/durft u met een <u>andere</u> rollator te lopen waar apparatuur op is bevestigd?

☐ Ja

☐ Nee

Bent u in staat/durft u met een <u>uw eigen</u> rollator te lopen waar apparatuur op bevestigd wordt?

☐ Ja

☐ Nee

Bent u in staat/wilt u één of meerdere wandelingen maken op één dag?

☐ Ja

☐ Nee

Vul hier uw telefoon nummer en/of e-mail in

Telefoon nummer:

E-mail:

Dit is het einde van de vragenlijst.
Hartelijk bedankt voor het invullen van deze vragenlijst!

A.5. Accelerometer app alternatives

Accelerometer Monitor, Mobile Tools.

- Output as .txt file.
- Time saved as difference between measurements in milliseconds. No clock-time.
- $X(m/s^2)$, $Y(m/s^2)$ and $Z(m/s^2)$

The Accelerometer Monitor did not give a clock-time bases time stamp, therefore it was hard to link it to the GPS data. Also the .txt output needed some processing before use.

Accelerometer Monitor, keuwlsoft Tools.

- Option to safe output on the phone, but only limited amount of readings were done. Then no output was generated any more.
- Output as .txt file
- Time as seconds passed. No clock-time
- $X(m/s^2)$, $Y(m/s^2)$, $Z(m/s^2)$ and $R(m/s^2)$, Theta(deg) and Phi(deg) As given by the application itself.

The Accelerometer Monitor from Keuwlsoft stopped measuring after a random amount of time, so could not be trusted. Also, no clock based time stamp was provided which made it harder to link to the GPS data.

AcMeter

- No function to save data

The AcMeter showed the accelerometer output of the phone on screen, but did not contain a function to save the data. It was not the only application that had only this function, but an example for the many applications that can be found on-line.

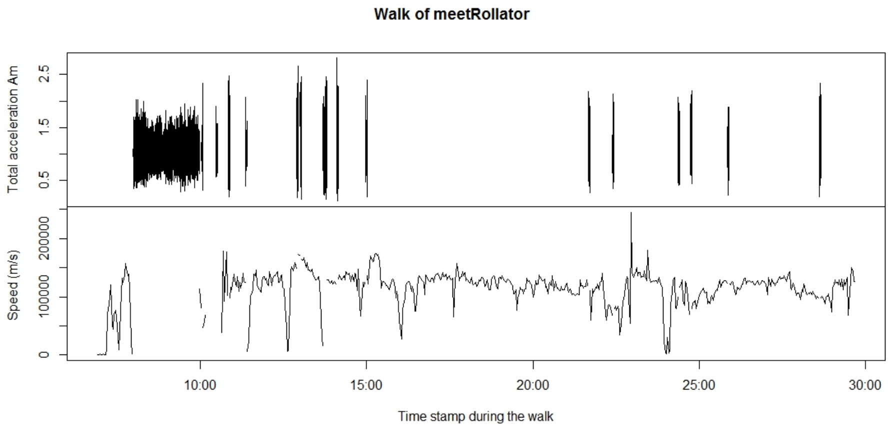
A.6. Interviews with elderly list of possible obstacles

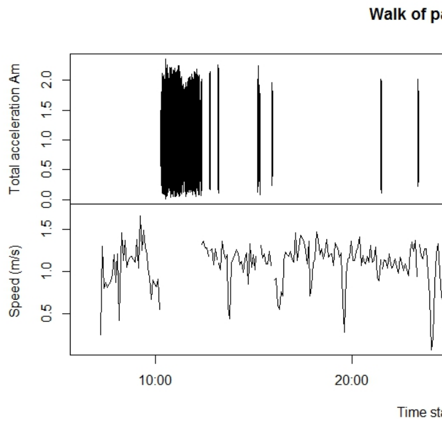
1. = never
2. = rarely
3. = sometimes
4. = often
5. = always

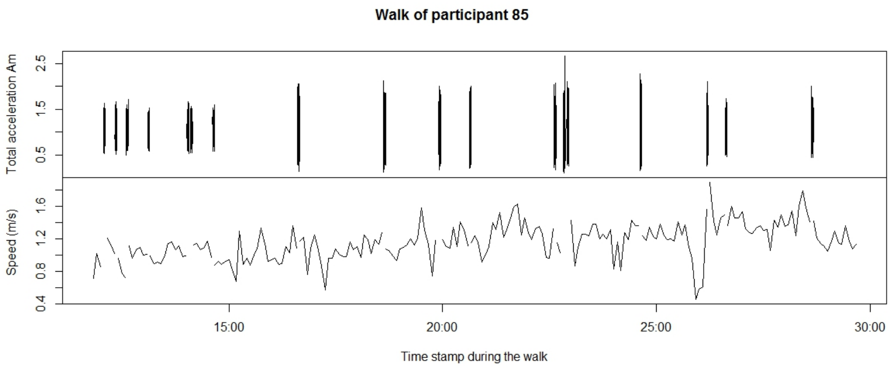
Table A.1.: Average score per possible problem

	Average score
Quality of the side walk	
Bad maintenance of side walks	4
Narrow side walks	1
too few curb ramps	3.5
Sloping side walks	2.5
Too steep slopes	3
Crossings on bad location	1
unclear crossings	1
Not enough time for crossing	2.5
Mixed use of space	3
Bikers on the side walk	2
Objects	
Wrongly parked cars	4
Wrongly parked bikes and scooters	1.5
Drain covers	1
poles on the side walk	2
Dog poop	1
Not enough resting benches	1
Not enough public rest-rooms	2
Not enough shelter by rain	1.5
protruding portals, facades, basement windows	3
Overall	
A lot of pedestrians	3
A lot of noise	3
A lot of traffic	1.5
Safety	
Scary alleys	1
Bad lightening by evening/night	1
loiterers	1.5
Unsafe feeling	1.5
Environment	
A lack of green	1
Bad maintenance	1
Ugly buildings	1.5
Litter	1
Garbage bags	1.5
Wind	1.5

A.7. Failed measurements



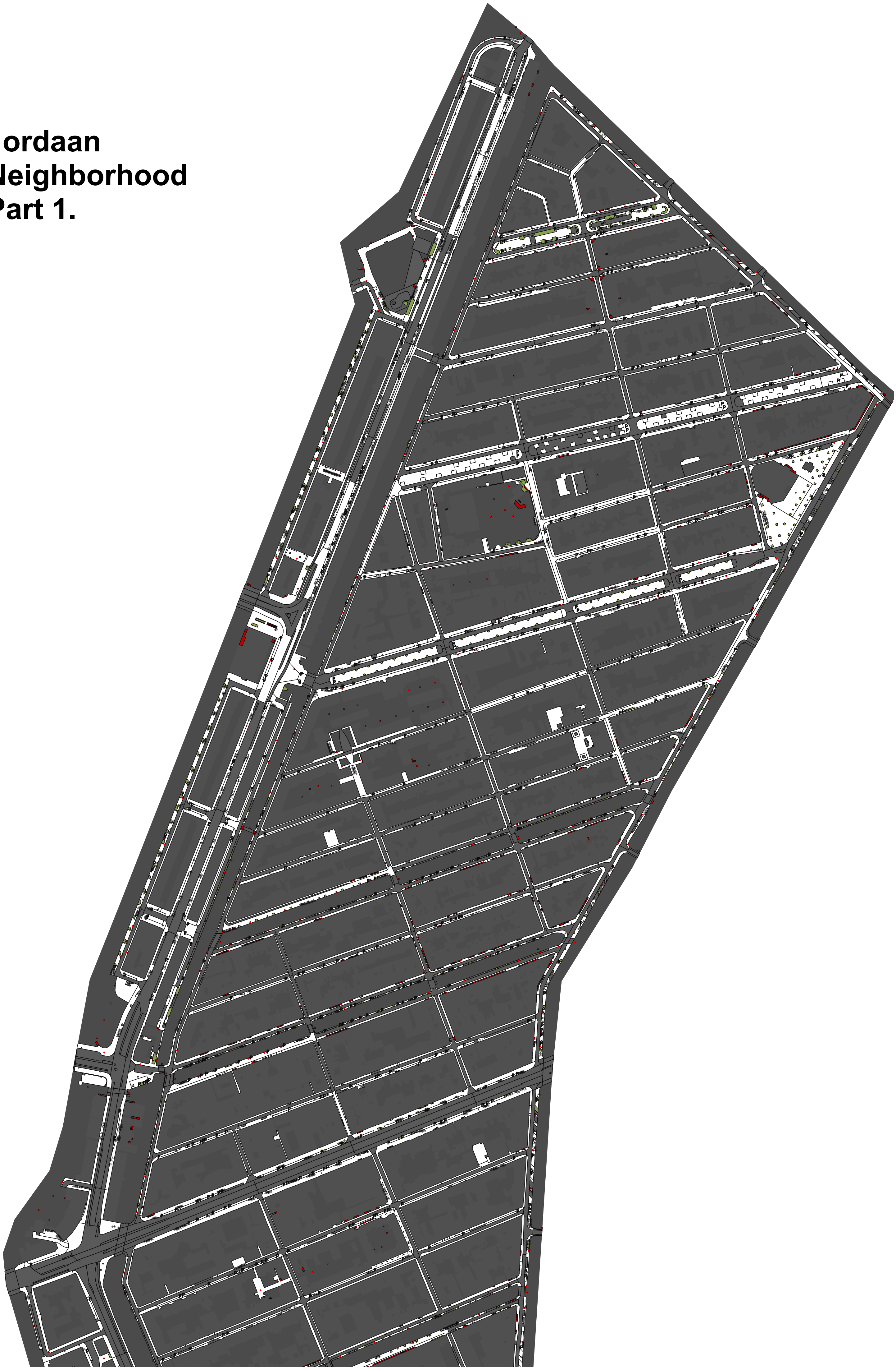


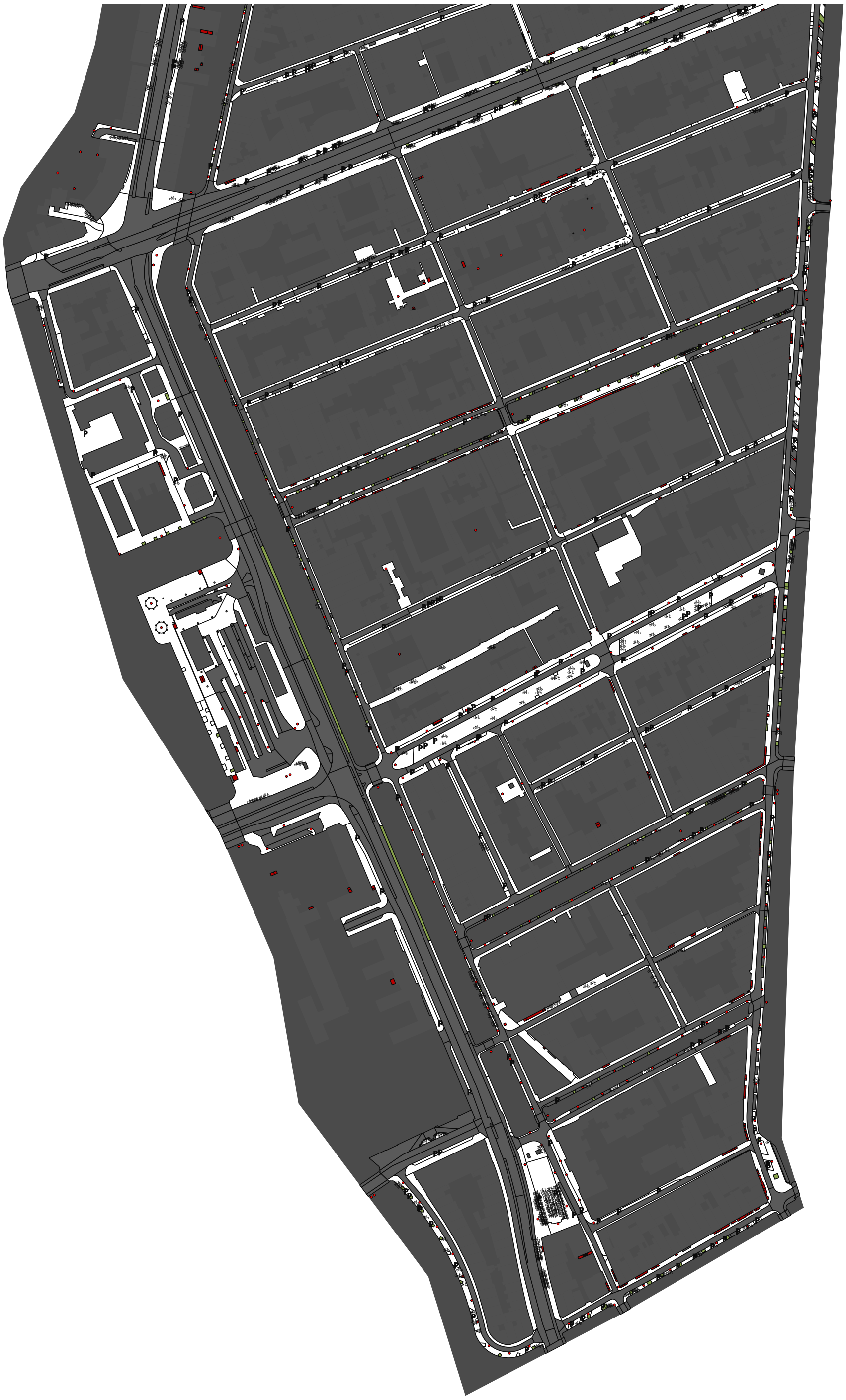


A.8. Jordaan road classification total

??

Jordaan Neighborhood Part 1.





Jordaan Neighborhood Part 2.

80 0 80 160 240 320 m

Legend

- Parking plot Bike
- Parking plot car
- Street Furniture
- Stairs
- Bordes
- Buildings
- Jordaan Neighborhood

Roads

- 1 Fast Transport (Car, Bike, Public Transport)
- 2 Pedestrian area
- 3 Unpaved

A.9. Detail of AHN2 of Jordaan

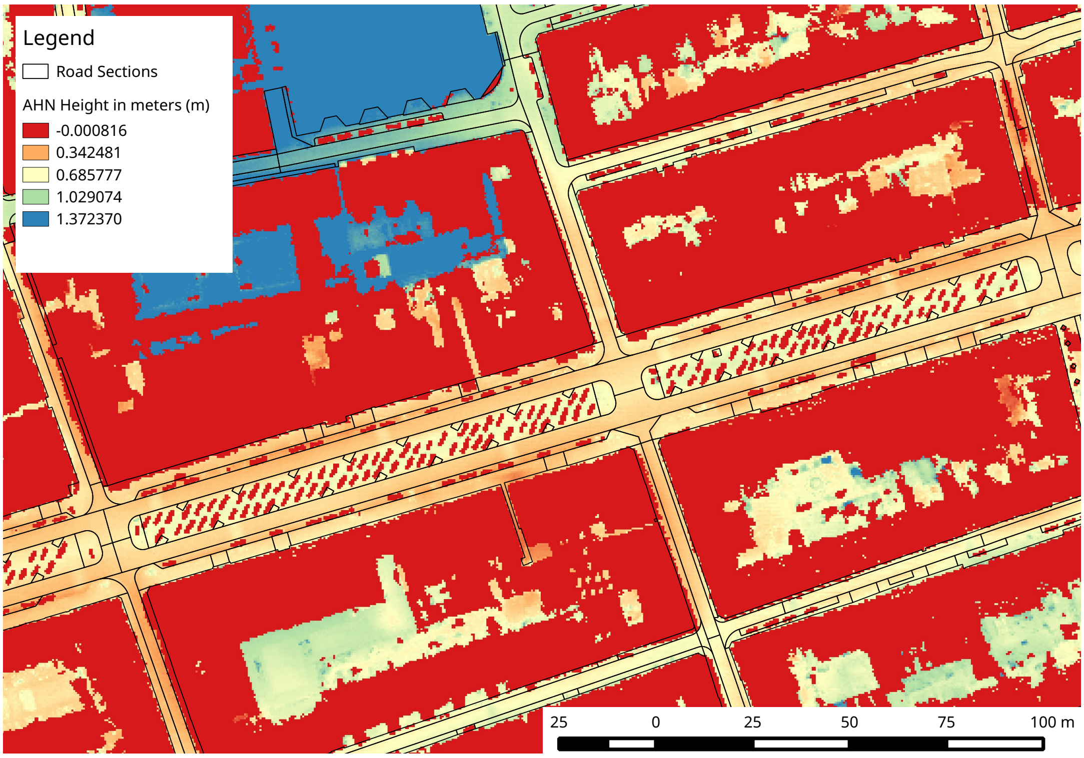


Figure A.1.: Detail Jordaan height map

img/R_comparisonMethodsSpeed2.pdf

A.10. Change Point methods tests for Speed